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CHORD FACTORS K_p FOR HARMONICS AT DIFFERENT PITCHES

q.														y/τ_{max}																									
1	3/3																															2/3						
2	6/6																5/6															4/6						
3	9/9											8/9										7/9										6/9						
4	12/12								11/12								10/12								9/12							8/12						7/12
5	15/15						14/15							13/15						12/15							11/15						10/15				9/15		
6	18/18					17/18						16/18					15/18					14/18						13/18					12/18						
7	21/21				20/21					19/21					18/21				17/21					16/21					15/21				14/21						
8	24/24			23/24					22/24				21/24				20/24				19/24				18/24					17/24			16/24			15/24			14/24
9	27/27		26/27					25/27				24/27				23/27		22/27				21/27				20/27					19/27		18/27		17/27			16/27	
10	30/30	29/30					28/30				27/30			26/30			25/30			24/30			23/30				22/30					21/30	20/30	19/30			18/30		
y/τ_{max}	1.0	967	964	959	952	945	934	926	917	905	906	889	875	867	857	852	833	815	810	800	792	779	767	762	750	741	734	722	712	709	705	700	667	639	630	625	600	592	584
1	1.0	999	998	998	997	996	995	993	991	989	988	985	981	978	975	973	966	958	956	951	947	940	934	931	924	919	914	906	901	897	894	891	866	839	839	831	809	800	793
3	1.0	988	985	981	975	966	951	940	924	901	891	865	831	809	782	766	707	643	623	586	556	500	454	434	383	342	309	259	222	195	174	156	0.0	156	174	195	309	[illegible]	383
5	1.0	966	958	947	931	906	866	835	793	733	707	643	556	500	434	396	259	116	075	0.0	065	174	259	295	383	447	500	574	623	660	690	707	866	966	974	982	1.0	998	993
7	1.0	943	918	897	866	819	743	686	609	500	454	342	177	105	0.0	058	259	449	500	588	659	766	839	866	924	958	978	996	1.0	998	993	988	866	629	588	559	309	225	139
9	1.0	897	866	831	782	707	598	500	383	223	156	0.0	191	304	434	500	707	866	901	951	981	1.0	998	975	924	866	804	707	623	556	500	454	0.0	358	407	462	500	755	875
11	1.0	839	802	750	680	574	407	297	131	075	156	342	556	660	782	795	966	998	989	951	897	766	629	583	383	231	105	087	222	321	396	454	866	999	994	981	809	724	618
13	1.0	777	727	659	563	423	208	058	131	365	454	643	831	914	975	993	966	802	733	588	442	174	052	148	383	550	669	818	901	947	973	988	866	371	284	195	309	459	598
15	1.0	707	643	556	434	259	0.0	174	383	624	707	866	981	1.0	975	940	707	342	223	0.0	195	500	707	782	924	981	1.0	966	907	831	766	707	0.0	696	760	831	1.0	982	930
17	1.0	629	550	442	295	087	208	396	609	826	891	985	981	914	782	686	259	231	365	588	752	940	999	997	924	802	669	423	222	065	058	156	866	940	848	831	309	100	113
19	1.0	545	999	321	149	087	407	597	793	956	988	985	831	669	434	207	259	727	826	951	948	940	777	680	383	116	105	423	623	752	835	891	866	072	047	194	809	952	989
21	1.0	454	342	195	0.0	259	588	766	924	1.0	988	866	556	309	0.0	174	707	985	1.0	951	831	500	156	0.0	383	643	804	966	1.0	981	940	891	0.0	881	935	981	809	628	402
23	1.0	358	231	064	149	423	743	894	991	956	891	643	195	105	434	597	966	918	826	588	321	174	545	680	924	998	978	819	623	442	287	156	866	792	696	555	309	566	778
25	1.0	299	116	064	295	574	866	973	991	826	707	342	195	500	782	894	966	550	365	0.0	321	766	966	[illegible]	924	727	500	087	222	442	597	707	866	061	383	555	1.0	951	809
27	1.0	170	0.0	195	434	707	951	1.0	924	624	454	0.0	556	809	975	1.0	707	0.0	223	558	831	1.0	897	782	383	0.0	305	707	901	981	1.0	988	0.0	983	1.0	981	309	025	356
29	1.0	052	116	321	563	819	995	973	793	365	156	342	831	978	975	894	259	550	733	951	918	766	358	148	383	727	914	996	901	752	597	454	866	569	412	194	809	965	995
31	1.0	052	231	442	680	906	995	894	109	075	156	643	781	978	782	597	259	918	989	951	752	174	358	583	924	998	914	574	222	065	287	454	866	517	673	831	809	525	162
33	1.0	156	342	556	782	966	951	766	333	223	454	866	[illegible]	809	434	174	707	985	901	588	195	500	891	975	924	643	309	259	623	831	940	988	0.0	992	944	831	309	666	910
35	1.0	259	449	659	866	996	836	597	131	500	707	985	831	500	0.0	287	966	721	500	0.0	442	940	966	866	383	116	500	906	1.0	947	835	707	866	294	079	194	1.0	905	637
37	1.0	358	550	750	931	996	743	396	131	793	891	985	556	105	434	686	966	231	075	588	897	940	545	295	383	802	978	906	623	321	058	156	866	855	884	981	309	150	577
39	1.0	454	643	831	975	966	588	174	383	901	983	866	195	309	782	940	707	342	623	951	981	500	156	434	924	985	809	259	222	556	766	891	0.0	909	780	555	805	990	939
41	1.0	545	727	841	997	906	407	058	004	989	988	643	195	669	97.	933	259	802	956	951	659	174	777	931	924	550	105	574	901	998	973	891	866	010	264	555	809	414	088
43	1.0	629	802	947	997	819	208	287	793	989	891	342	556	914	975	795	259	948	456	588	065	766	949	931	383	231	669	996	901	660	396	156	866	916	990	981	309	754	984
45	1.0	767	866	981	925	707	0.0	530	924	901	707	0.0	831	1.0	792	500	707	866	623	0.0	556	1.0	707	434	383	866	1.0	707	222	145	500	707	0.0	739	523	194	1.0	844	262
47	1.0	777	918	998	931	574	208	686	94.	733	454	342	981	914	434	058	966	449	075	588	947	766	052	295	924	958	669	087	623	897	993	988	866	312	575	831	305	273	762
49	1.0	839	959	998	866	423	407	135	991	500	156	643	981	669	0.0	396	966	116	500	951	947	174	629	866	224	597	105	819	1.0	897	090	454	866	994	979	831	809	1.0	823
51	1.0	891	985	981	782	259	588	740	924	225	156	866	831	309	434	766	707	643	901	951	556	500	988	975	383	342	809	966	623	195	174	454	0.0	501	203	194	805	297	333
53	1.0	934	998	997	680	087	743	993	793	075	454	985	556	105	782	973	259	958	989	588	065	940	839	583	383	919	978	423	222	660	894	989	866	585	818	981	309	721	997
55	1.0	966	998	897	563	087	866	993	605	365	707	985	195	500	975	973	259	958	733	0.0	659	940	259	148	924	918	500	423	901	998	894	707	866	979	853	555	1.0	771	187
57	1.0	988	985	831	434	255	951	940	383	624	891	866	195	809	975	766	707	643	223	588	981	500	454	782	924	342	309	966	901	556	174	156	0.0	215	141	555	309	407	899
59	1.0	999	958	756	295	423	995	835	131	826	988	643	556	978	782	396	956	116	365	951	847	174	934	997	383	597	914	819	222	321	690	891	866	863	965	981	809	994	777
61	1.0	999	978	659	149	574	[illegible]	686	131	956	998	342	831	978	434	058	966	449	826	951	442	766	934	680	383	958	914	087	623	947	993	891	866	872	625	194	809	175	557
63	1.0	988	866	556	0.0	707	051	500	383	1.0	891	0.0	981	809	0.0	500	707	866	1.0	588	195	1.0	454	0.0	924	866	309	707	1.0	831	500	156	0.0	091	468	831	309	899	947
65	1.0	966	802	442	149	844	366	287	609	956	707	[illegible]	[illegible]	[illegible]	434	795	259	998	826	0.0	752	766	259	680	924	231	500	996	623	055	396	707	866	946	997	831	1.0	689	063

TABLE - F-1

VALUES OF K_{dn} FOR INTEGRAL-SLOT, 3ϕ WINDINGS - - TABLE F-2

n	K_{dn} - HARMONIC DISTRIBUTION FACTORS								
q=	2	3	4	5	6	7	8	9	10	∞
1	.966	.960	.958	.957	.957	.957	.956	.955	.955	.955
3	.707	.667	.654	.646	.644	.642	641	.640	.63[illegible]	.636
5	.259	.217	.205	.200	.197	.195	.194	.194	.193	.191
7	-.259	-.177	-.158	-.149	-.145	-.143	-.141	-.140	-.140	-.1[illegible]
9	-.707	-.333	-.270	-.247	-.236	-.229	-.225	-.222	-.220	-.212
11	-.966	-.177	-.126	-.110	-.102	-.097	-.095	-.093	-.092	-.087
13	-.966	.217	.126	.102	.092	.086	.083	.081	.079	.073
15	-.707	.667	.270	.200	.172	.158	.150	.145	.141	.127
17	-.259	.960	.158	.102	.084	.075	.070	.066	.064	.056
19	.259	.960	-.205	-.110	-.084	-.072	-.066	-.062	-.060	-.059
21	.707	.667	-.654	-.247	-.172	-.143	-.127	-.118	-.112	-.091
23	.966	.217	-.958	-.149	-.092	-.072	-.063	-.057	-.054	-.041
25	.966	-.177	-.958	.200	.102	.075	.063	.056	.052	.038
27	.707	-.333	-.654	.646	.236	.158	.127	.111	.101	.071
29	.259	-.177	-.205	.957	.145	.086	.066	.056	.050	.033
31	-.259	.217	.158	.957	-.197	-.097	-.070	-.057	-.050	-.031
33	-.709	.667	.270	.646	-.644	-.229	-.150	-.118	-.101	-.058
35	-.966	.960	.126	.200	-.957	-.143	-.083	-.062	-.052	-.027
37	-.966	.960	-.126	-.149	-.957	.195	.095	.066	.054	.026
39	-.707	.667	-.270	-.247	-.644	.642	.225	.145	.112	.049
41	-.259	.217	-.158	-.110	-.197	.957	.141	.081	-.060	.023
43	.259	-.177	.205	.102	.145	.957	-.194	-.093	-.064	-.022
45	.707	-.333	.654	.200	.236	.642	-.641	-.222	-.141	-.042
47	.966	-.177	.958	.102	[illegible]	.195	-.956	-.140	[illegible]	-.020
49	.966	.217	.958	-.110	-.092	-.143	-.956	.194	.092	.019
51	.707	.667	.654	-.247	-.172	-.229	-.641	.640	.220	.038
53	.259	.960	.205	-.149	-.084	-.097	-.194	.955	.140	.018
55	-.259	.960	-.158	.200	.084	.086	.141	.955	-.193	-.017
57	-.707	.667	-.270	.646	.172	.158	.225	.640	-.639	-.033
59	-.966	.217	-.126	.957	.092	.075	.095	.194	-.955	-.016
61	-.966	-.177	.126	.957	-.102	-.072	-.083	-.140	-.955	.016
63	-.707	-.333	.270	.646	-.236	-.143	-.150	-.222	-.639	.030
65	-.259	-.177	.158	.200	-.145	-.072	-.070	-.093	-.193	.015

ROUND COPPER WIRE TABLE F-3

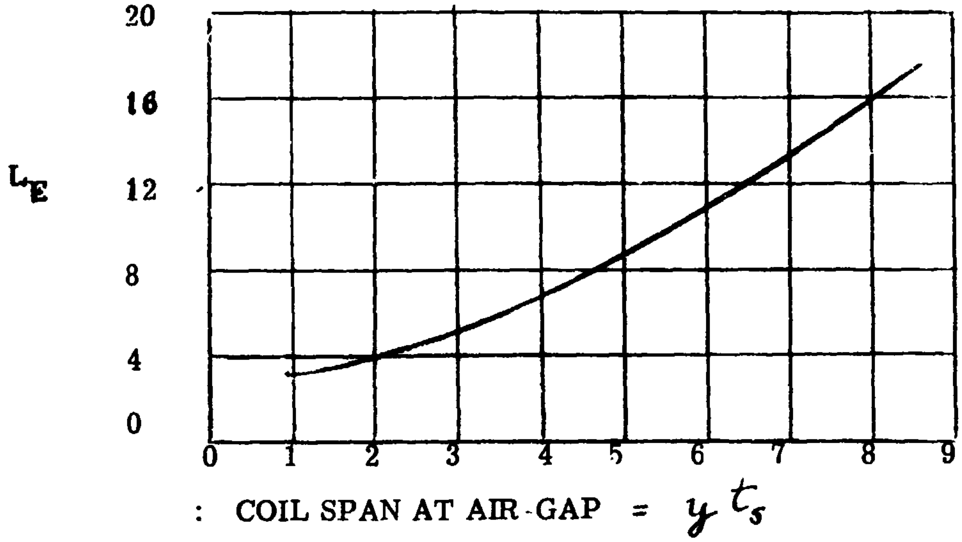
SIZE AWG	BARE DIAMETER	AREA □"	Ω/1000' @25°C	SINGLE FORMVAR	HEAVY FORMVAR	SINGLE GLASS FORMVAR	BARE WT. #/1000'	SINGLE GLASS SILICONE	DOUBLE GLASS SILICONE
36	.0050	.0000196	424	.0056	.0060		.0757		
35	.0056	.0000246	338	.0062	.0066		.0949		
34	.0063	.0000312	[illegible]	.0070	.0074		.1201		
33	.0071	.0000396	210	.0079	.0084		.1526		
32	0080	.0000503	165	.0088	.0094	.0121	.1937		
31	.0089	.0000622	134	.0097	.0104	.0130	.2398		
30	.0100	.0000785	106	0108	.0116	.0142	.3025	.0132	[illegible]
29	.0113	.000100	831	.0122	.0130	.0156	.3866	.0145	0165
28	.0126	.000125	66.4	.0135	.0144	.0169	.4806	.0158	.0178
27	.0142	.000158	52 6	.0152	.0161	.0186	.6101	.0174	.0194
26	0159	.000199	41 7	.0169	.0179	.0203	.7650	.0191	.0211
25	.0179	.000252	33 0	.0190	.0200	.0224	.970	.0211	0231
24	0201	.000317	26.2	.0213	0223	.0263	1.273	.0251	.0276
23	.0226	.000401	20.7	0238	.0249	.0289	1.546	0276	.0301
22	0254	.000507	16.4	.0266	.0277	.0317	1.937	.0303	.0328
21	.0285	.000638	13 0	.0299	.0310	.0349	2.459	.0335	.0360
20	0320	.000804	10.[illegible]	.0334	.0346	.0384	3.099	.0370	0395
19	0360	.00102	8.14	.0374	.0386	.0424	3.900	0409	0434
18	.0403	.00126	6 59	.0418	.0431	.0468	4.914	.0453	.0478
17	0453	.00159	5 22	.0469	0482	0519	6.213	0503	0528
16	0508	.00204	4 07	.0524	.0538	0575	7.812	0558	0583
15	0571	.00255	3 26	.0588	.0602	.0639	9.87	.062	0646
14	0641	.00322	2.58	.0659	.0673	.0710	12.44	.0691	0716
13	.072	.00407	2.04	.0738	.0753	0789	15.69	.0770	.0795
12	.0808	.00515	1.61	.0827	.0842	.0877	19.76	0858	0883
11	.0907	.00650	1.28	.0927	.0942	.0977	24.90	.0957	0982
10	.102	.00817	1 02	.1039	.1055	.1089	31.43	.1069	.1094
9	.114	.0102	.814	.1165	.1181	.1225	39 62	.1204	.1254
8	.129	.0131	.654	.1306	.1323	.1366	49.98	.1345	.1395
7	.144	.0163	.510	.1465	.1482	.1525	63.03	.1503	.1553
6	.162	.0206	.403	.1643	.1661	.1703	79.44	.1680	.1730
5	.182	.0260	.319	.1842	.1861	.1902	100.2	.1879	.1929
4	.204	.0327	.254				126.3	.2103	.2153
3	.229	.0412	.202				159.3		
2	.258	.0523	.159				200.9		
0	.325	.0830	.100						
2/0	.365	.105	.0791						
4/0	.460	.166	.0500						

TABLE F-4

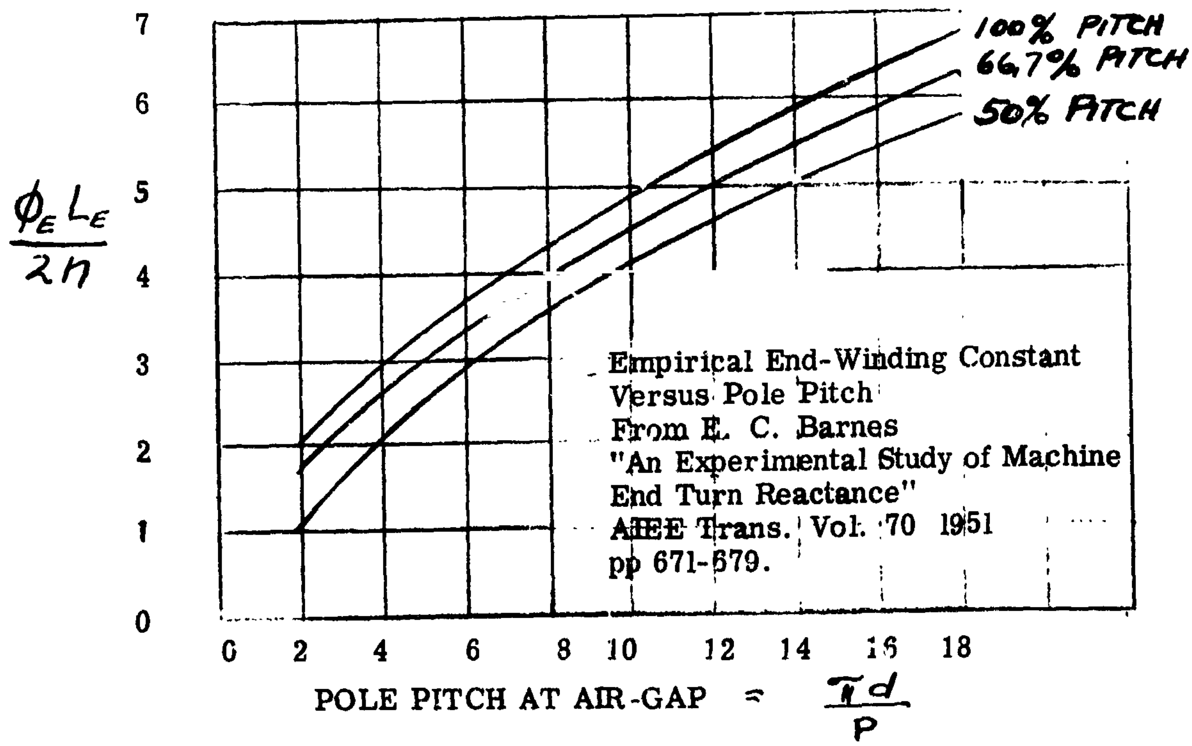
HALF-SIZE, ROUND, COPPER WIRE

SIZE AWG	BARE DIAMETER	AREA □"	BARE WT #/1000'	Ω/1000' @ 20°C
1/0½	.3071	.0741	285.5	.1100
1½	.2734	.0587	226.3	.1387
2½	.2435	.0466	179.5	.1749
3½	.2169	.0370	142.4	.2204
4½	.1931	.0293	112.9	.2781
5½	.1720	.0232	89.6	.3506
6½	.1532	.0184	71.0	.4419
7½	.1364	.0146	56.3	.5574
8½	.1215	.0116	44.7	.7025
9½	.1082	.0092	35.4	.8859
10½	.0963	.00728	28.1	1.118
11½	.0858	.00578	22.3	1.409
12½	.0764	.00458	17.7	1.778
13½	.0680	.00363	14.0	2.243
14½	.0606	.0288	11.1	2.824
15½	.0540	.00229	8.83	3.557
16½	.0481	.00182	7.00	4.482
17½	.0428	.00144	5.54	5.661
18½	.0381	.00114	4.39	7.143
19½	.0340	.000907	3.50	8.972
20½	.0302	.000716	2.76	11.37
21½	.0269	.000568	2.19	14.33
22½	.0240	.000452	1.74	18.01
23½	.0214	.000360	1.39	22.65
24½	.0190	.000284	1.09	28.73
25½	.0169	.000224	.864	36.31
26½	.0151	.000179	.690	45.49
27½	.0134	.000141	.544	57.75
28½	.0120	.000113	.436	72.02
29½	.0106	.000088	.340	92.27
30½	.0095	.000071	.273	114.85

CURVE F-1



20
16
L_E
12
8
4
0
0 1 2 3 4 5 6 7 8 9
COIL SPAN AT AIR-GAP = $y\, t_s$

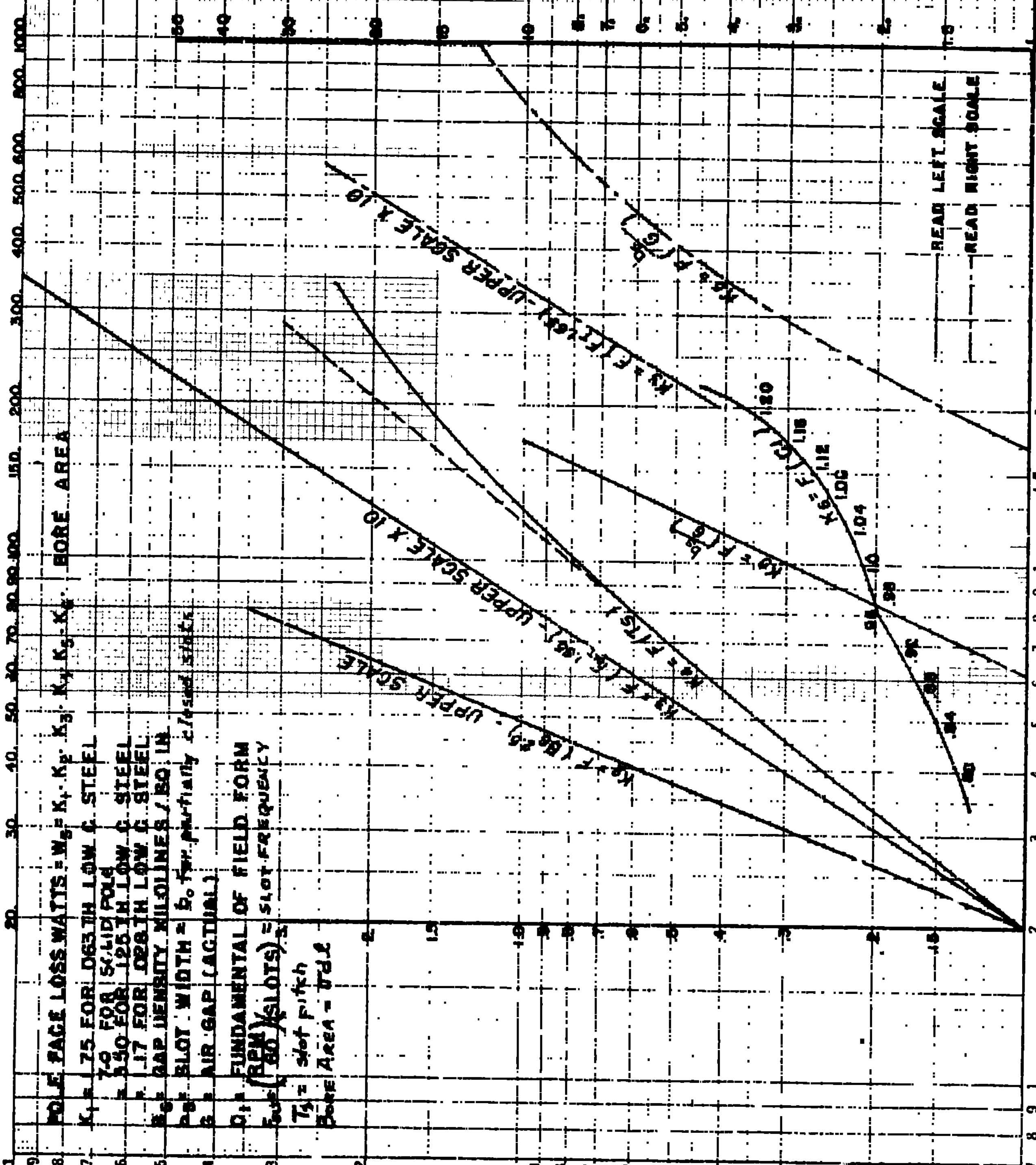


100% PITCH
66.7% PITCH
50% PITCH
7
6
5
$\frac{\phi_E L_E}{2n}$
4
3
2
1
0
0 2 4 6 8 10 12 14 16 18
POLE PITCH AT AIR-GAP = $\frac{\pi d}{P}$
Empirical End-Winding Constant
Versus Pole Pitch
From E. C. Barnes
"An Experimental Study of Machine
End Turn Reactance"
AIEE Trans. Vol. 70 1951
pp 671-679.

CURVE F-2

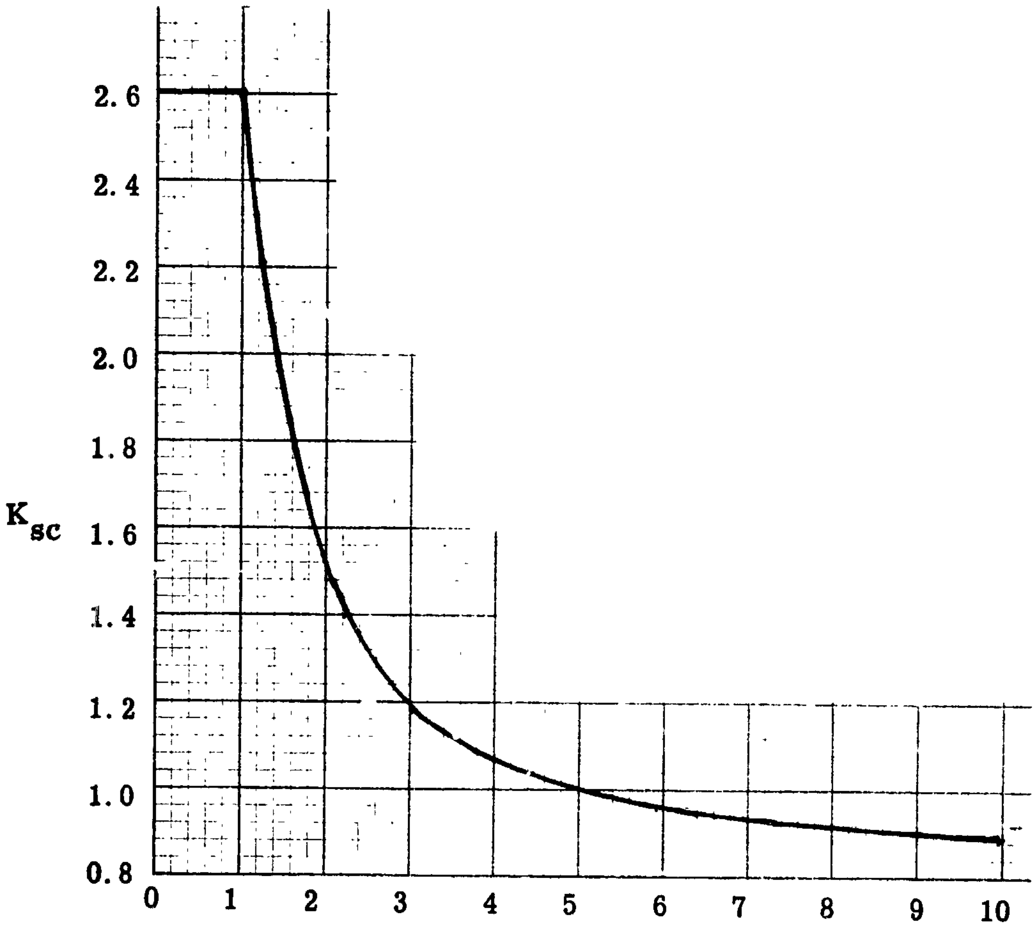
From Kennard and Spooner "Surface Iron Losses with Respect to Laminated Materials", Trans. AIEE, Vol. 43, 1924, pp 262-281.

REFER TO ITEM (186) IN SALIENT POLE DESIGN MANUAL FOR SAMPLE USE OF THIS CURVE

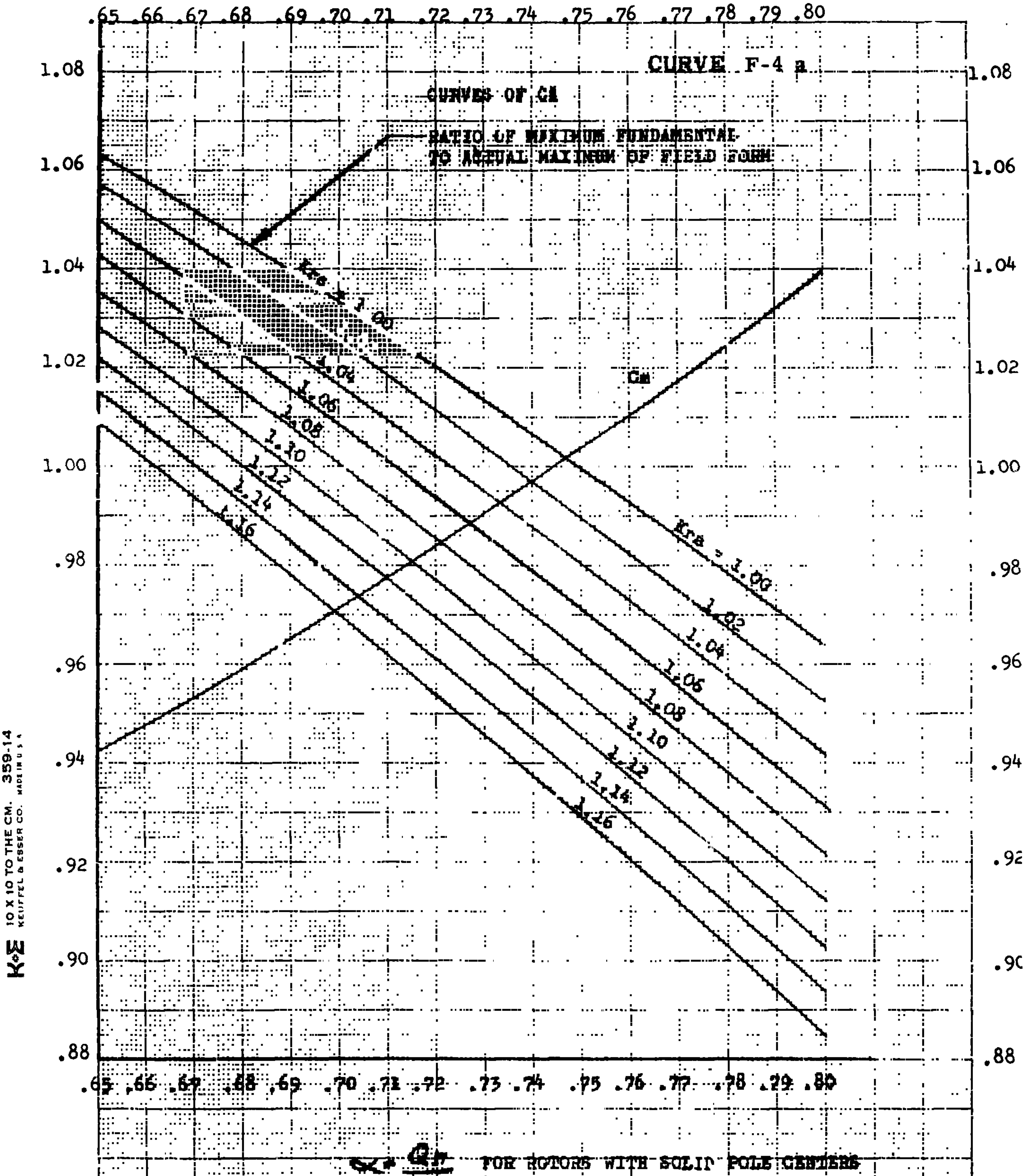


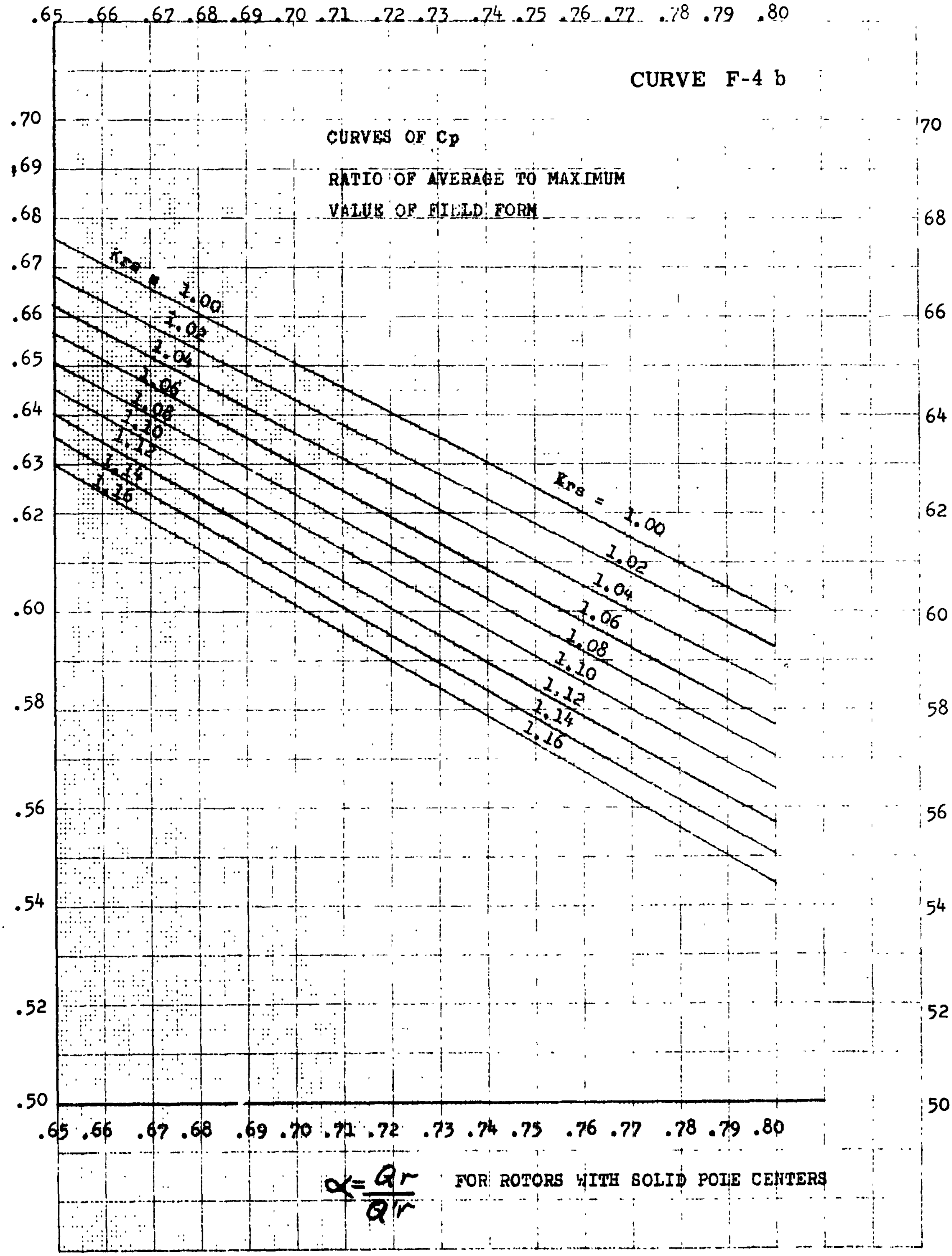
CURVE F-3

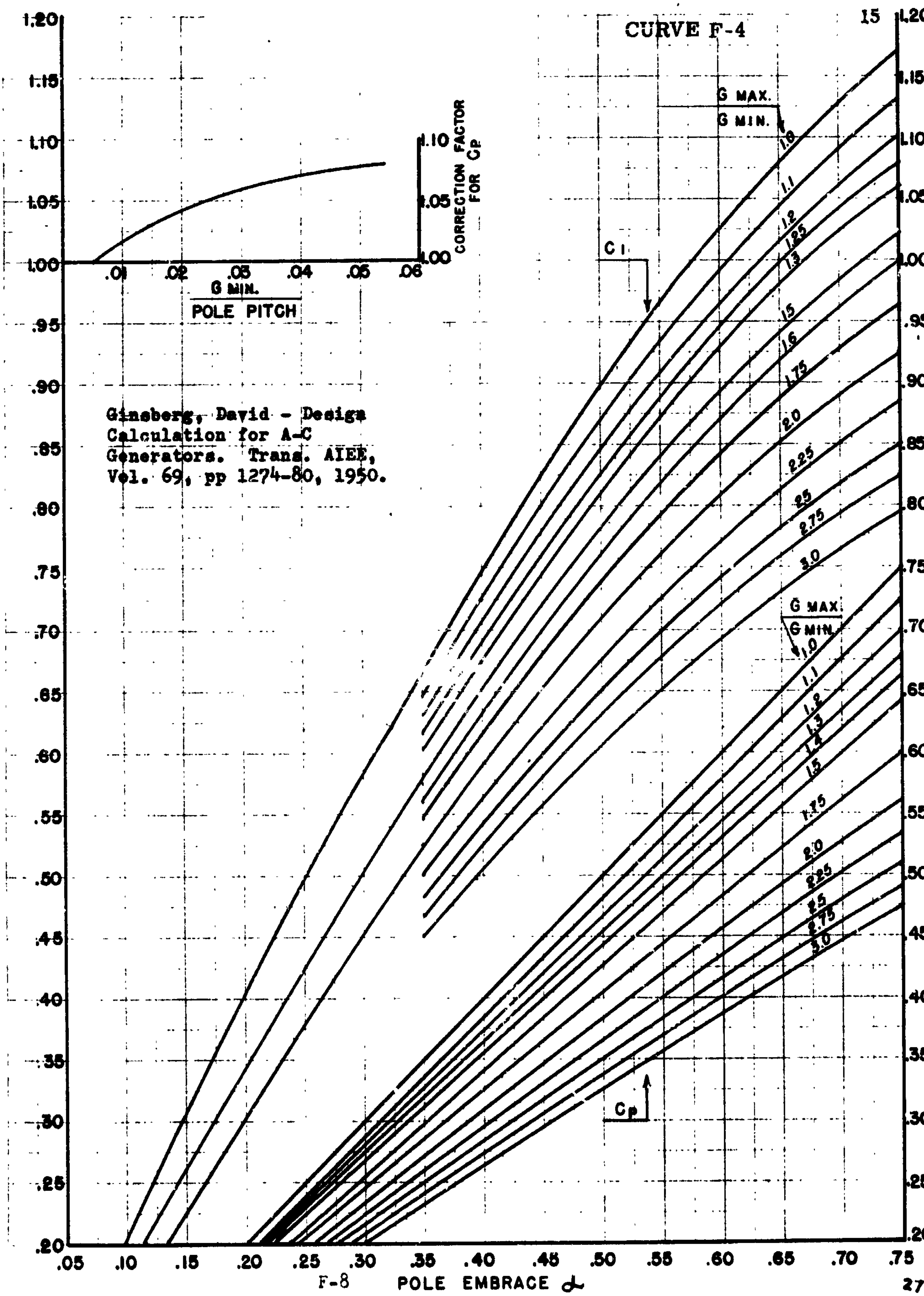
From E.I. Pollard "Load Losses In Salient-Pole Synchronous Machines" AIEE Trans. Vol. 54 1935 . PP 1332-1340



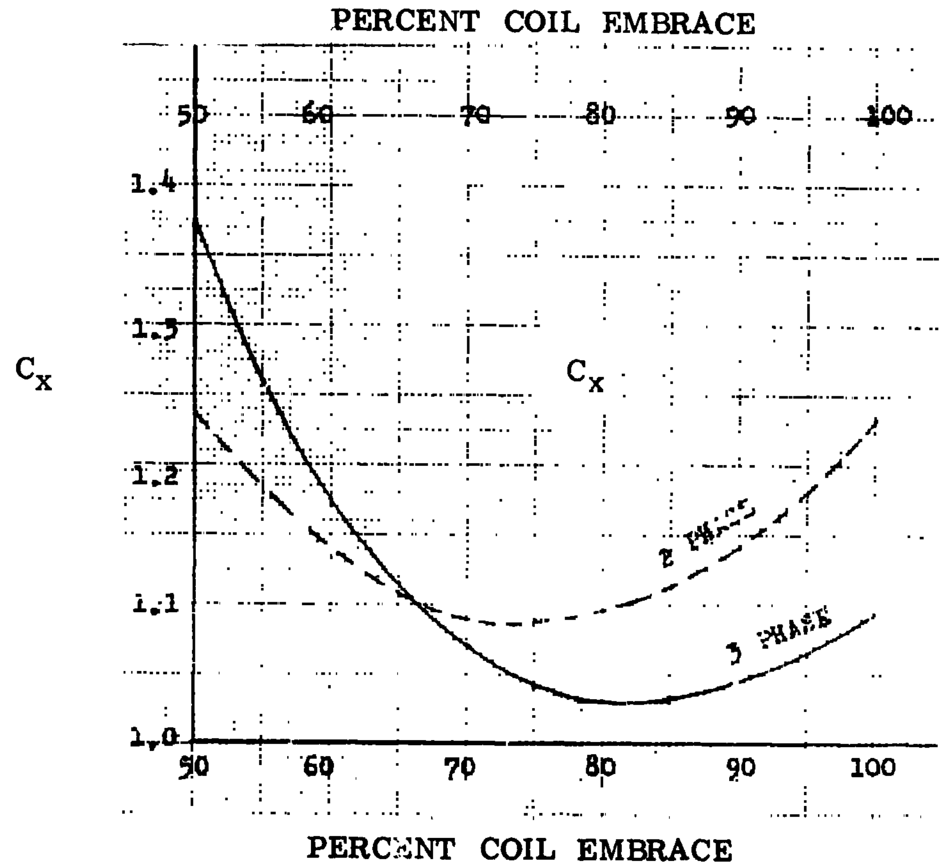
$b_s/g = \frac{\text{Slot opening}}{\text{air-gap}}$


CURVE F-4 a
CURVES OF Cm
RATIO OF MAXIMUM FUNDAMENTAL TO ACTUAL MAXIMUM OF FIELD FORM
Kra = 1.00
1.02
1.04
1.06
1.08
1.10
1.12
1.14
1.16
Cm
.65 .66 .67 .68 .69 .70 .71 .72 .73 .74 .75 .76 .77 .78 .79 .80
1.08
1.06
1.04
1.02
1.00
.98
.96
.94
.92
.90
.88
FOR ROTORS WITH SOLID POLE CENTERS


CURVE F-4 b
CURVES OF Cp
RATIO OF AVERAGE TO MAXIMUM
VALUE OF FIELD FORM
Krs = 1.00
1.02
1.04
1.06
1.08
1.10
1.12
1.14
1.16
$\alpha = \frac{Q_r}{Q'_r}$ FOR ROTORS WITH SOLID POLE CENTERS


CURVE F-4
Ginsberg, David - Design Calculation for A-C Generators. Trans. AIEE, Vol. 69, pp 1274-80, 1950.
CORRECTION FACTOR FOR Cp
G MIN. / POLE PITCH
.01 .02 .03 .04 .05 .06
1.00 1.05 1.10
G MAX. / G MIN.
1.0 1.1 1.2 1.25 1.3 1.5 1.6 1.75 2.0 2.25 2.5 2.75 3.0
C1
Cp
1.0 1.1 1.2 1.3 1.4 1.5 1.75 2.0 2.25 2.5 2.75 3.0
.20 .25 .30 .35 .40 .45 .50 .55 .60 .65 .70 .75 .80 .85 .90 .95 1.00 1.05 1.10 1.15 1.20
.05 .10 .15 .20 .25 .30 .35 .40 .45 .50 .55 .60 .65 .70 .75
POLE EMBRACE α

SLOT REACTANCE FACTOR



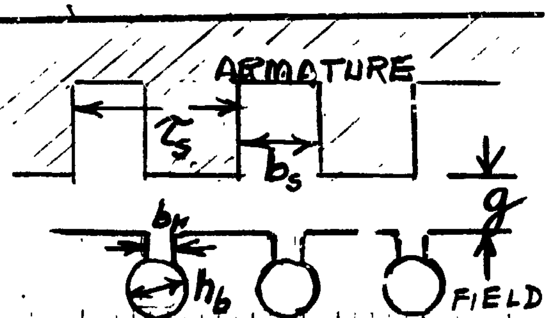
$$W_{DNL} = \frac{1.246\, p\, n_b\, l_b\, \rho}{a_b \times 10^3}\left[\tau_s B_g K_p K_g\right]^2 \times \left\{ K_{f1}\left[\frac{K_{W1}}{2\lambda_s + [\lambda_g/K_{\phi 1}]}\right]^2 + K_{f2}\left[\frac{K_{W2}}{2\lambda_s + [\lambda_g/K_{\phi 2}]}\right]^2 \right\}$$

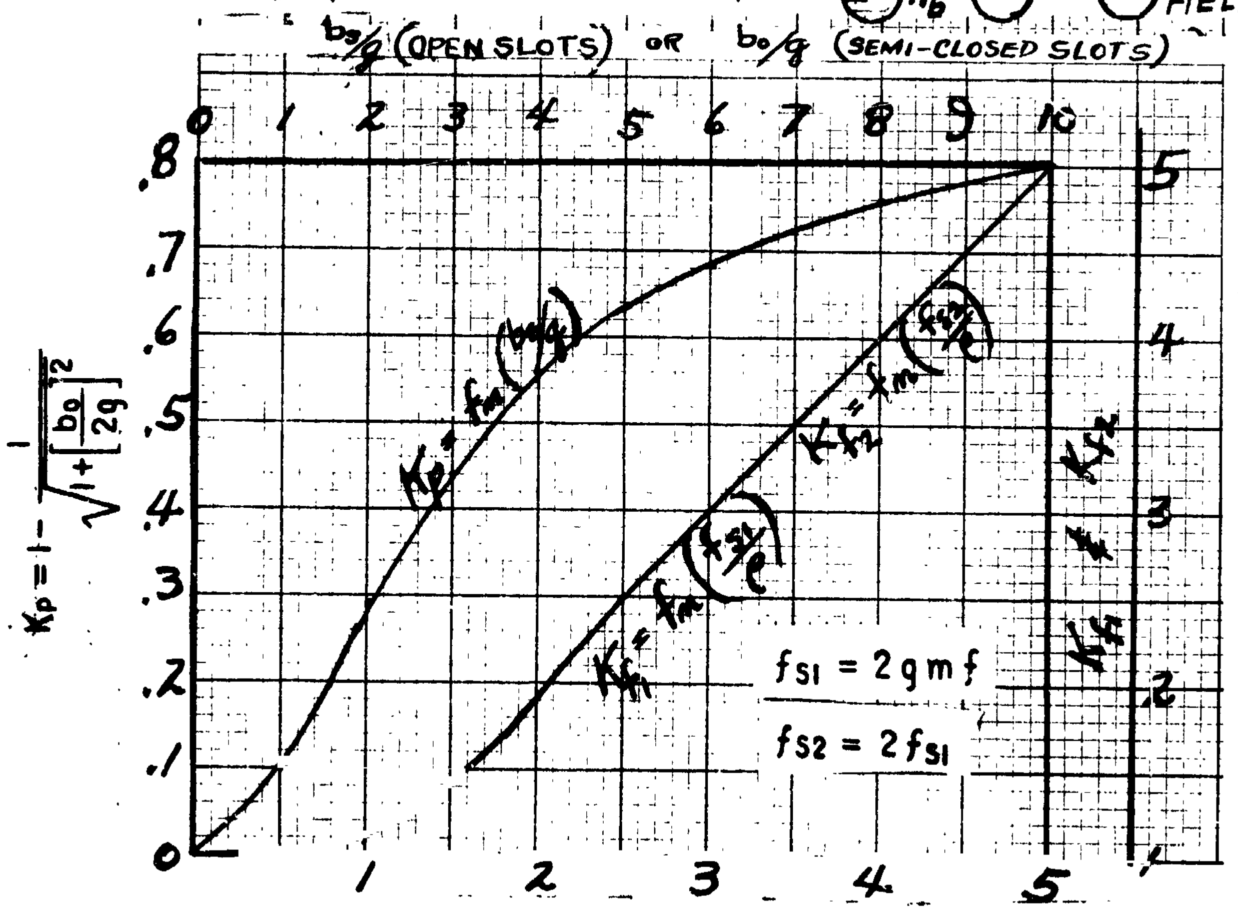
$$\lambda_s = \frac{h_r}{b_r} + \lambda_t + \lambda_c$$

$$\lambda_g = \frac{\tau_b}{K_g g}$$

$\lambda_c = .75/K_{f1}$ for round bars

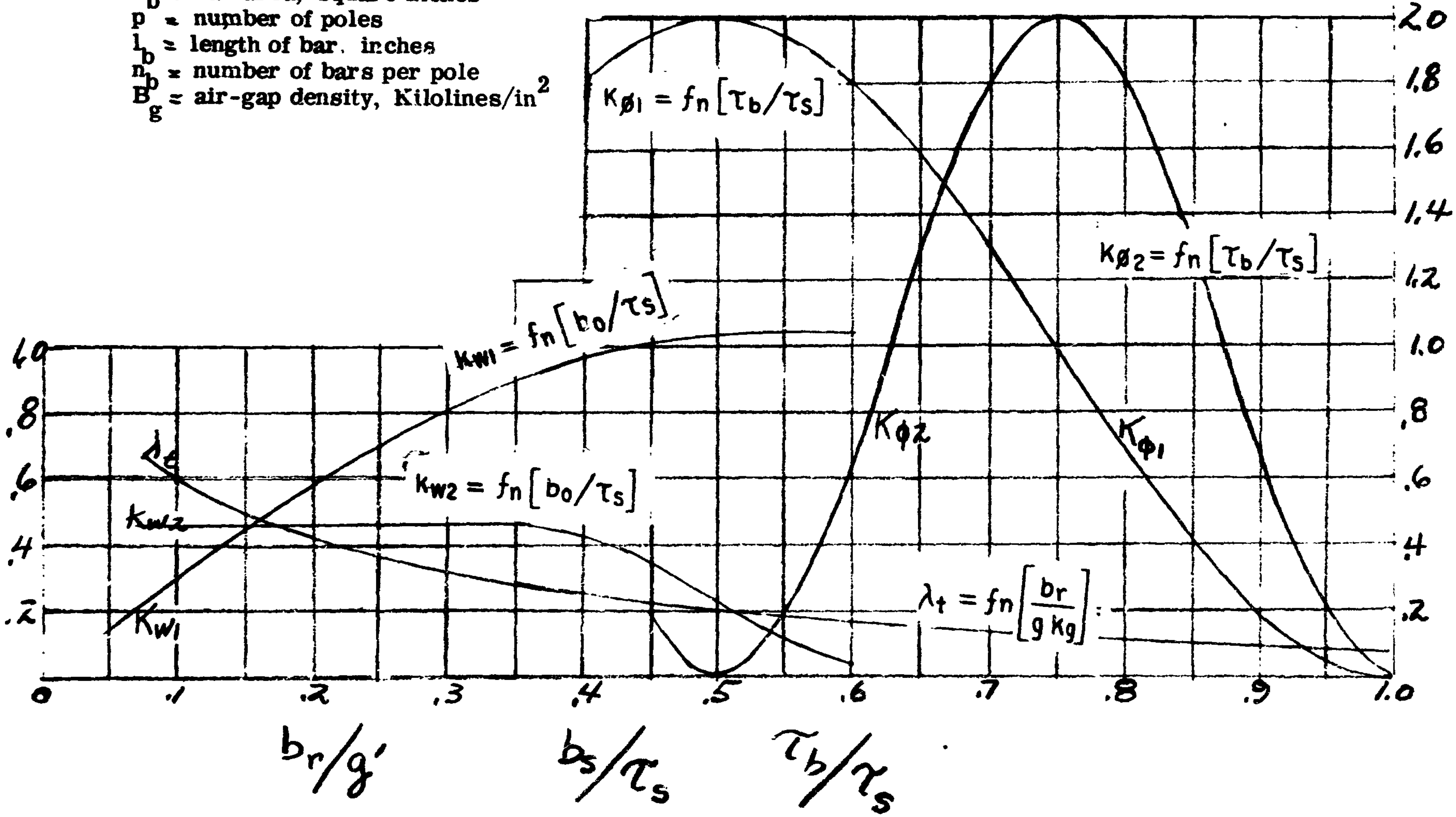
$\lambda_c = \dfrac{h_{b1}}{3 b_{b1} K_{f1}}$ for rectangular bars





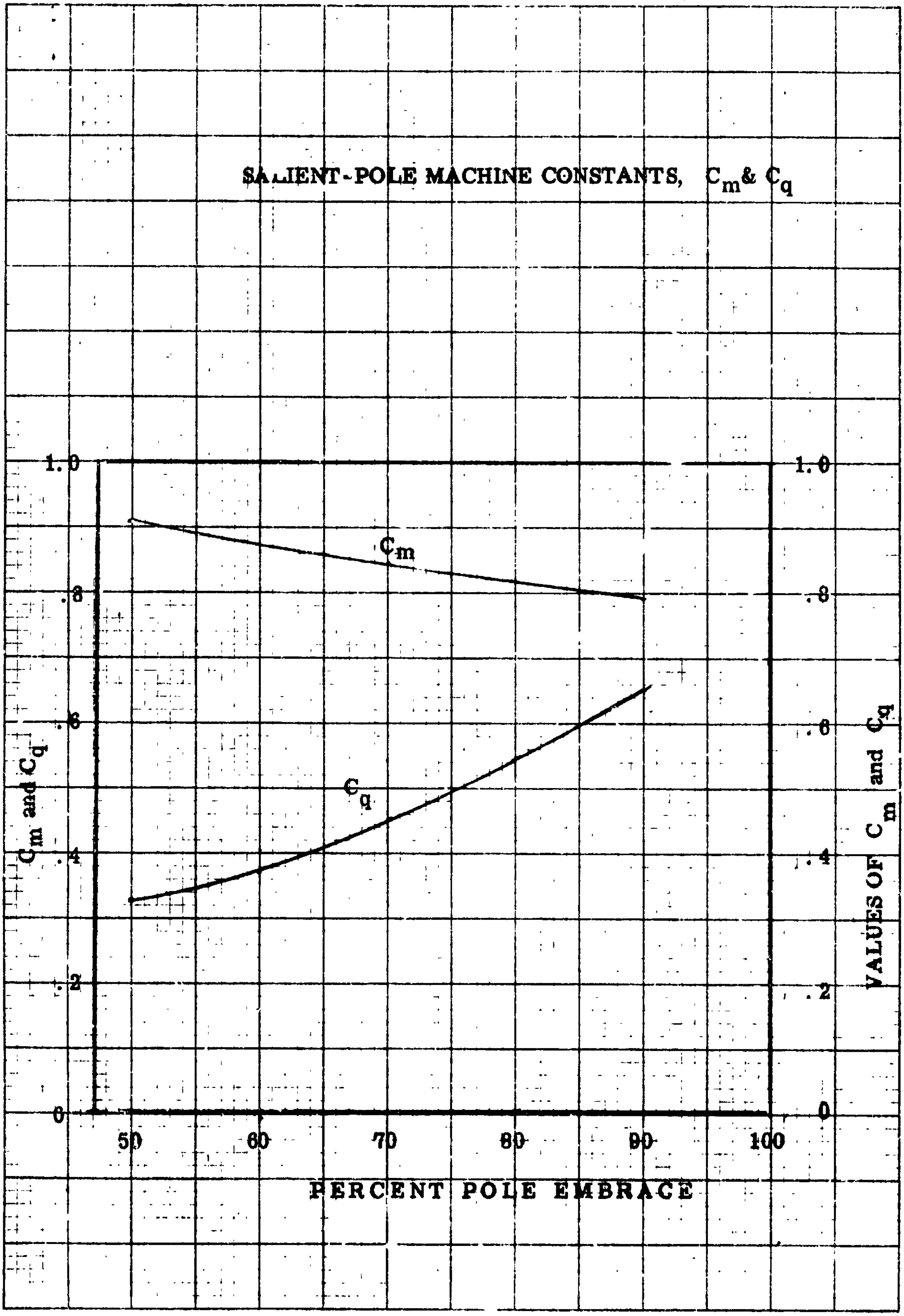
$$\delta_1 = .32\sqrt{\frac{f_{s1}}{\rho}} \times h_b \qquad \delta_2 = .32\sqrt{\frac{f_{s2}}{\rho}} \times h_b$$

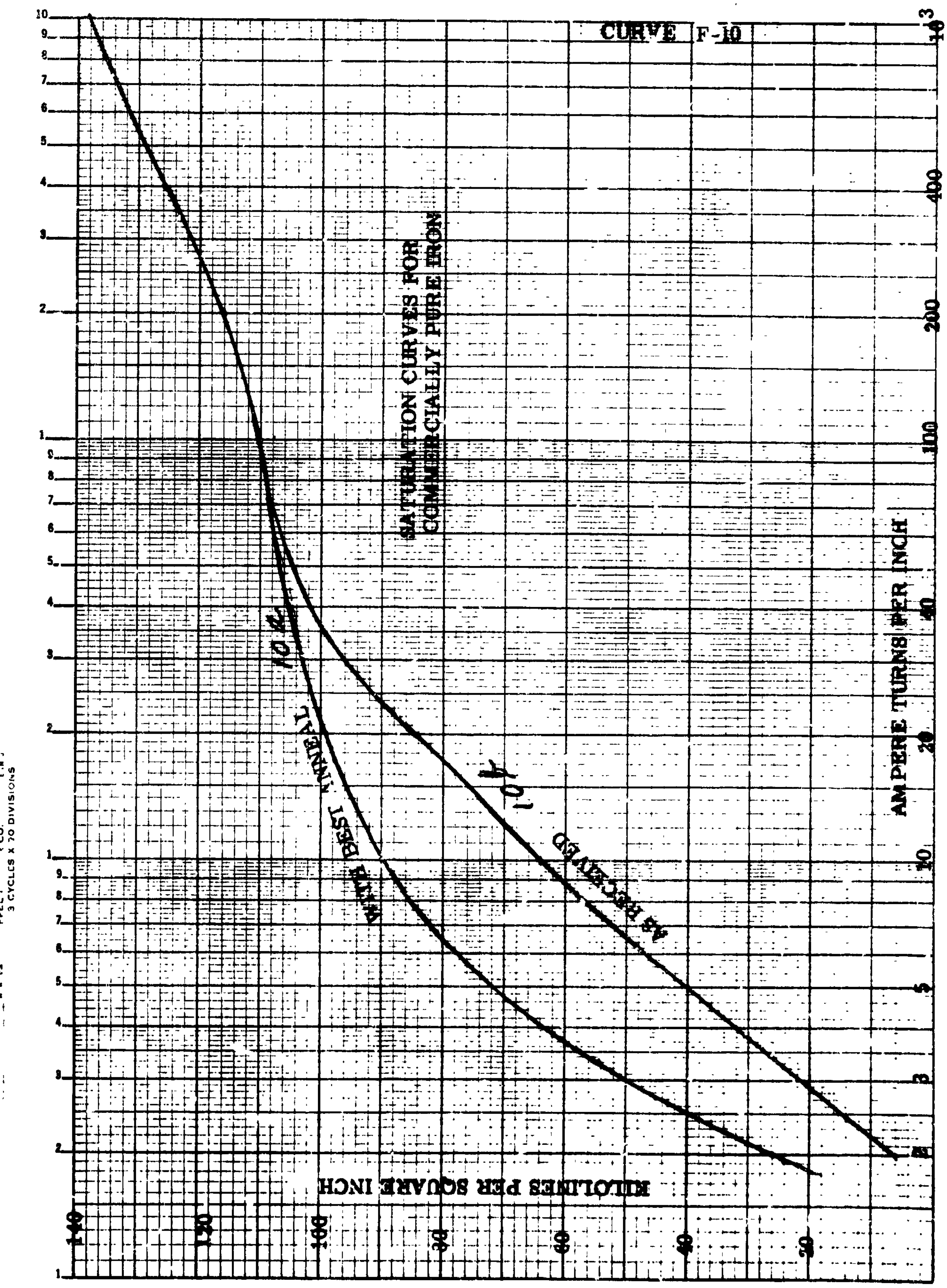
K_g = total Carter coefficient
ρ = damper bar resistivity, ohm-inch (10^{-6})
a_b = bar area, square inches
p = number of poles
l_b = length of bar, inches
n_b = number of bars per pole
B_g = air-gap density, Kilolines/in^2



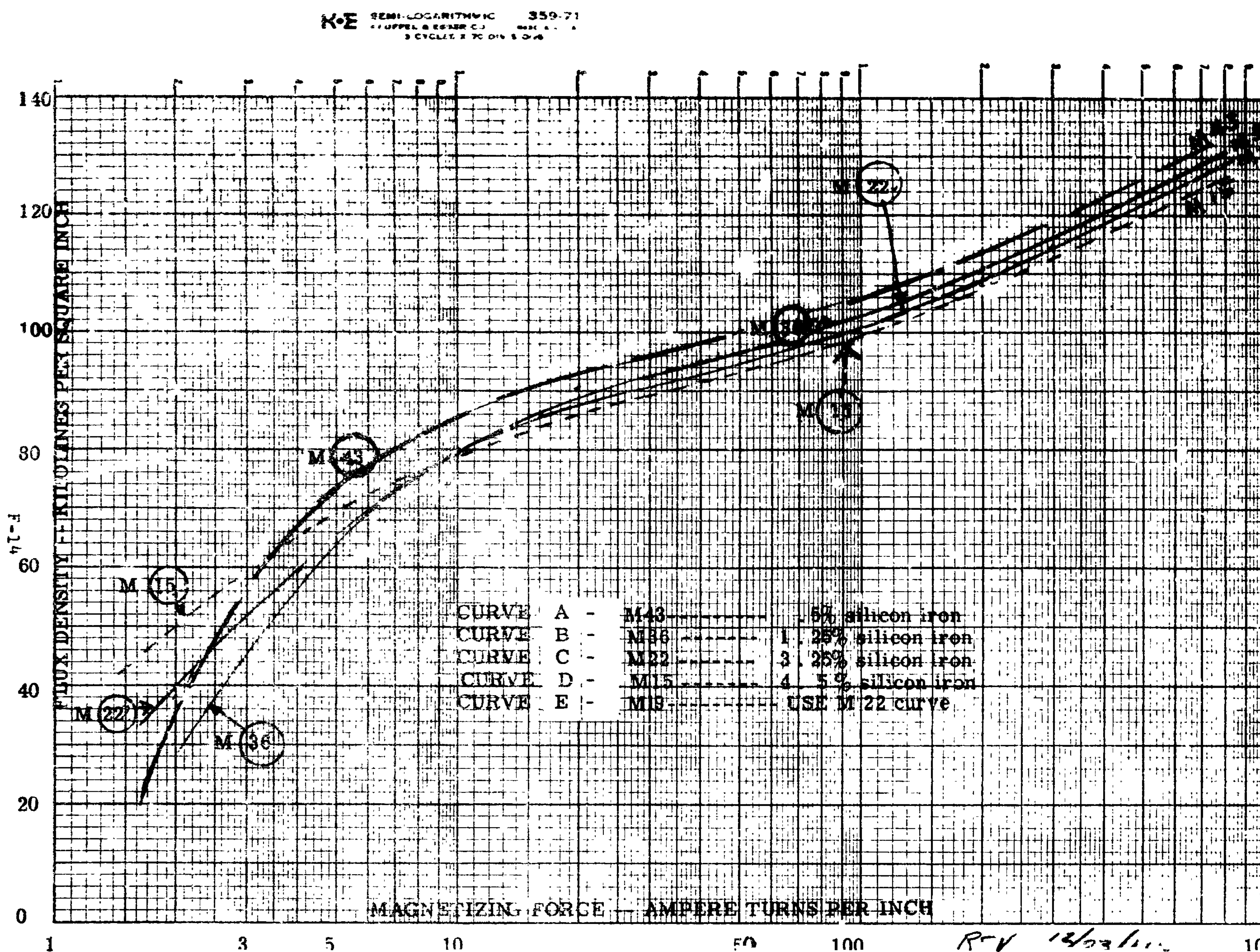
NO-LOAD DAMPER LOSS

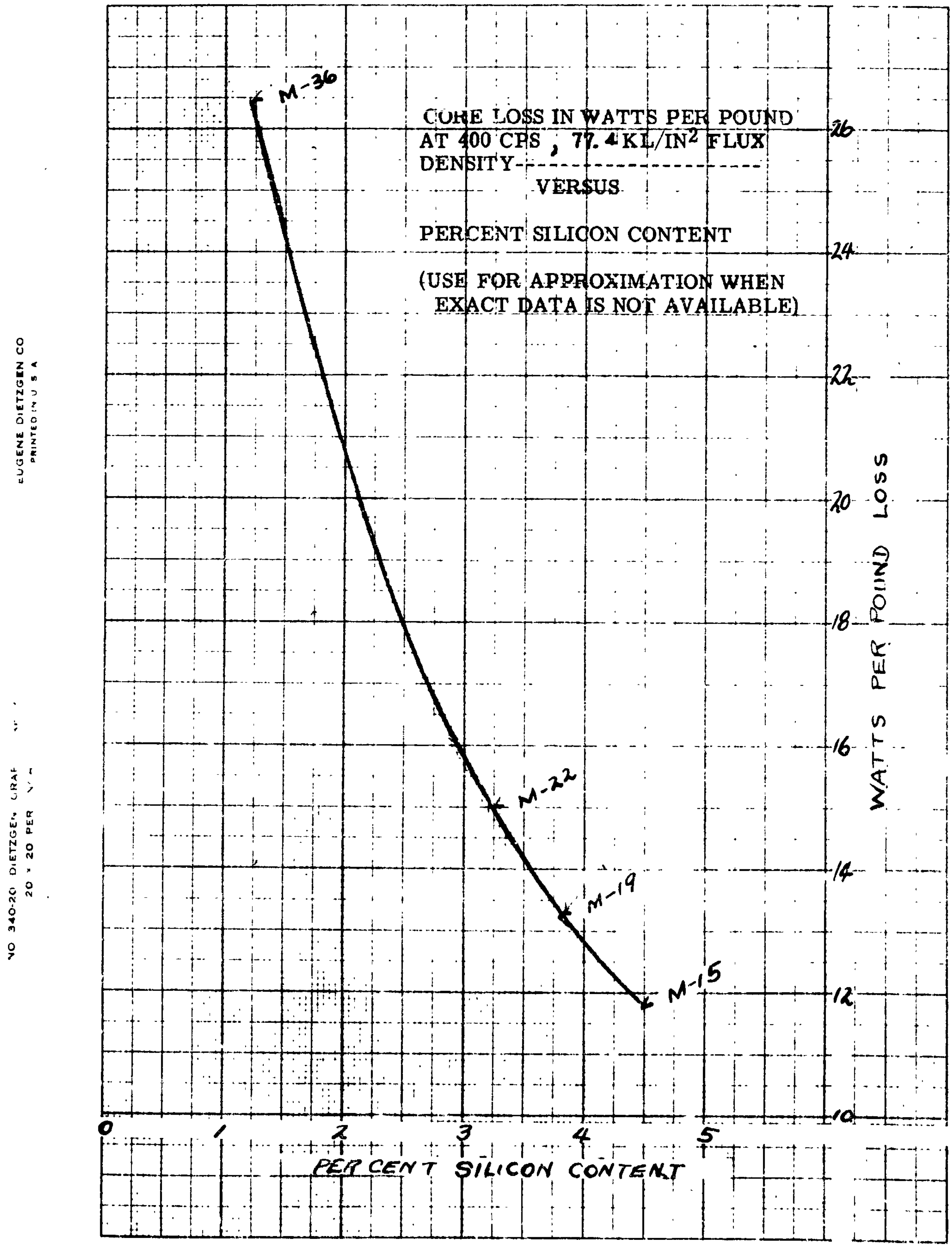
CURVE F-8

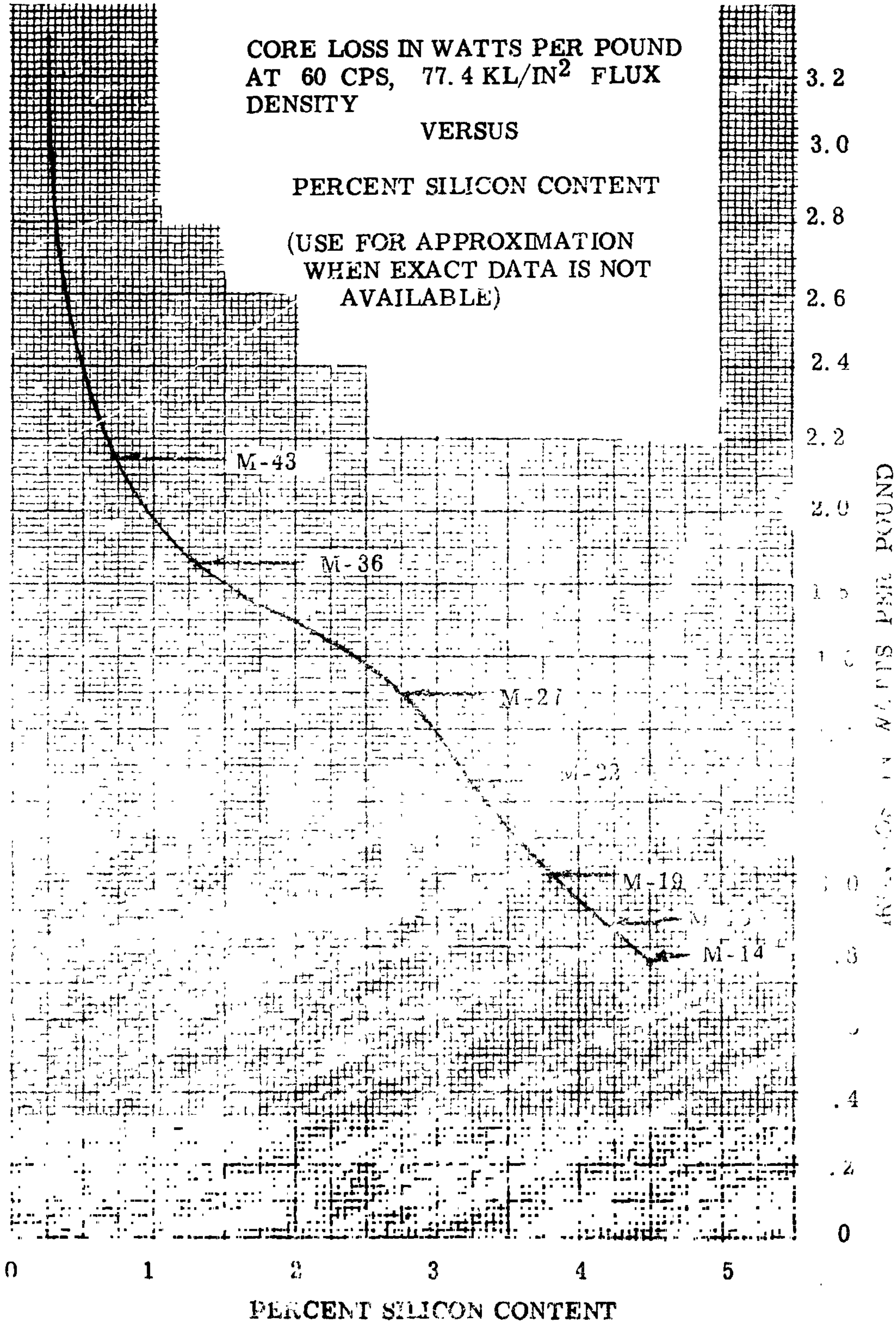

SALIENT-POLE MACHINE CONSTANTS, C_m & C_q
1.0
.8
.6
.4
.2
0
C_m
C_q
C_m and C_q
VALUES OF C_m and C_q
50
60
70
80
90
100
PERCENT POLE EMBRACE


CURVE F-10
SATURATION CURVES FOR COMMERCIALLY PURE IRON
AMPERE TURNS PER INCH
KILOLINES PER SQUARE INCH
WITH BEST ANNEAL
AS RECEIVED
140
120
100
80
60
40
20
2
3
5
10
20
40
100
200
400
1000
K&E SEMI-LOGARITHMIC 359-71
3 CYCLES X 70 DIVISIONS

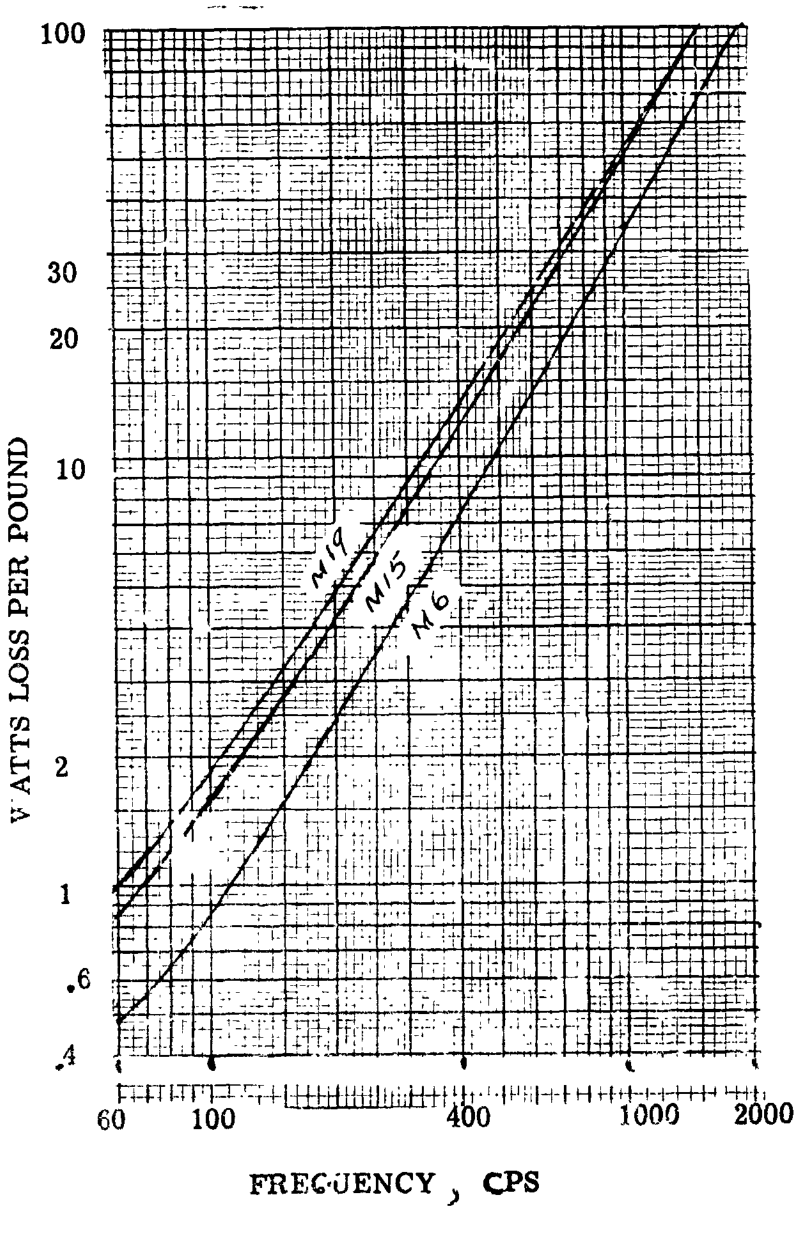
CURVE F-11


K•E SEMI-LOGARITHMIC 359-71
FLUX DENSITY -- KILOLINES PER SQUARE INCH
MAGNETIZING FORCE — AMPERE TURNS PER INCH
M 43
M 36
M 22
M 15
M 19
CURVE A - M43 ------ .5% silicon iron
CURVE B - M36 ------ 1.25% silicon iron
CURVE C - M22 ------ 3.25% silicon iron
CURVE D - M15 ------ 4.5% silicon iron
CURVE E - M19 ------ USE M 22 curve
R-V 12/23/...

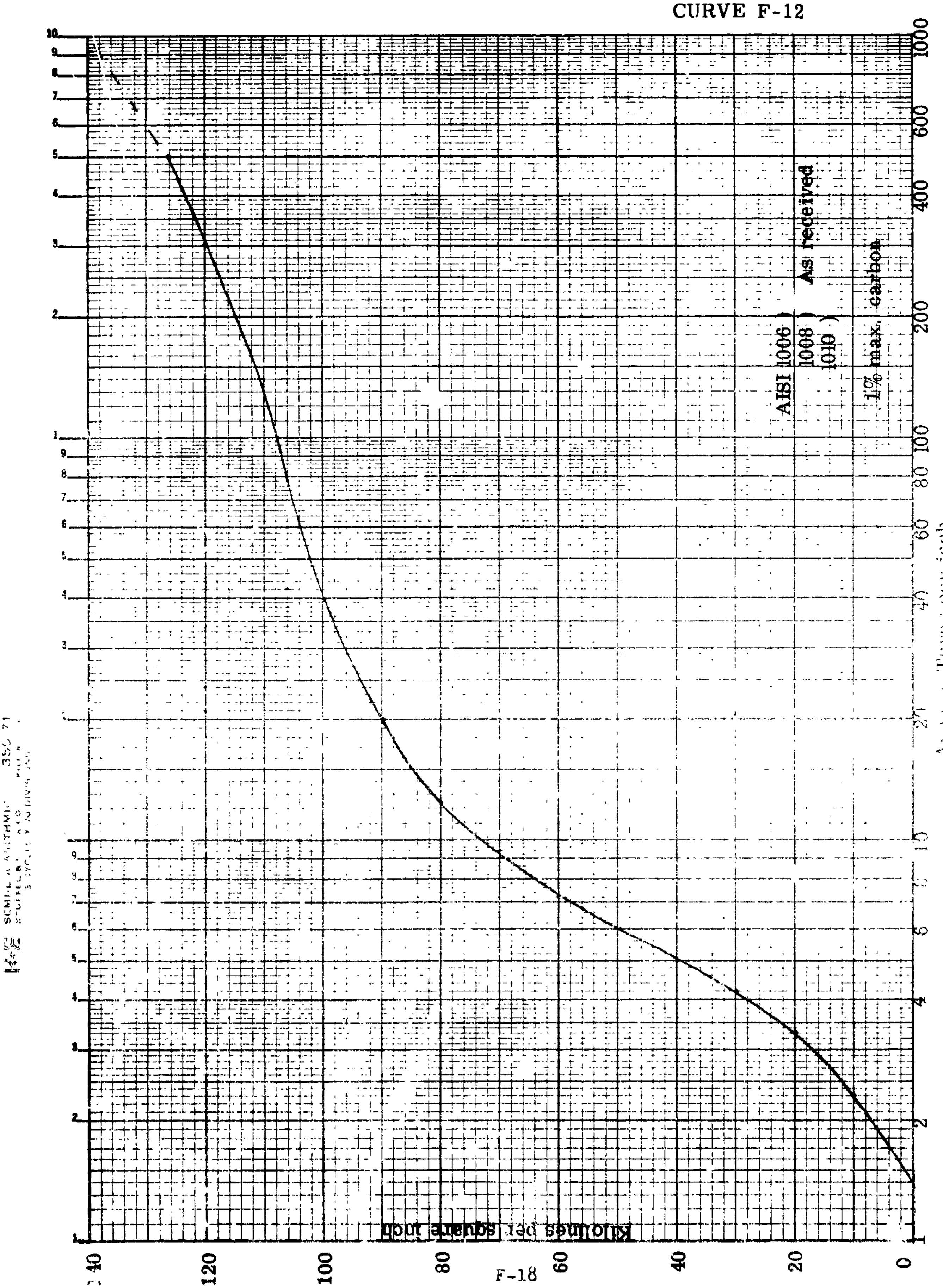

CORE LOSS IN WATTS PER POUND
AT 400 CPS , 77.4 KL/IN2 FLUX
DENSITY
VERSUS
PERCENT SILICON CONTENT
(USE FOR APPROXIMATION WHEN
EXACT DATA IS NOT AVAILABLE)
M-36
M-22
M-19
M-15
26
24
22
20
18
16
14
12
10
WATTS PER POUND LOSS
0
1
2
3
4
5
PERCENT SILICON CONTENT
EUGENE DIETZGEN CO
PRINTED IN U S A
NO 340-20 DIETZGEN GRAPH
20 X 20 PER


CORE LOSS IN WATTS PER POUND AT 60 CPS, 77.4 KL/IN² FLUX DENSITY
VERSUS
PERCENT SILICON CONTENT
(USE FOR APPROXIMATION WHEN EXACT DATA IS NOT AVAILABLE)
M-43
M-36
M-27
M-19
M-14
3.2
3.0
2.8
2.6
2.4
2.2
2.0
.8
.4
0
0
1
2
3
4
5
PERCENT SILICON CONTENT

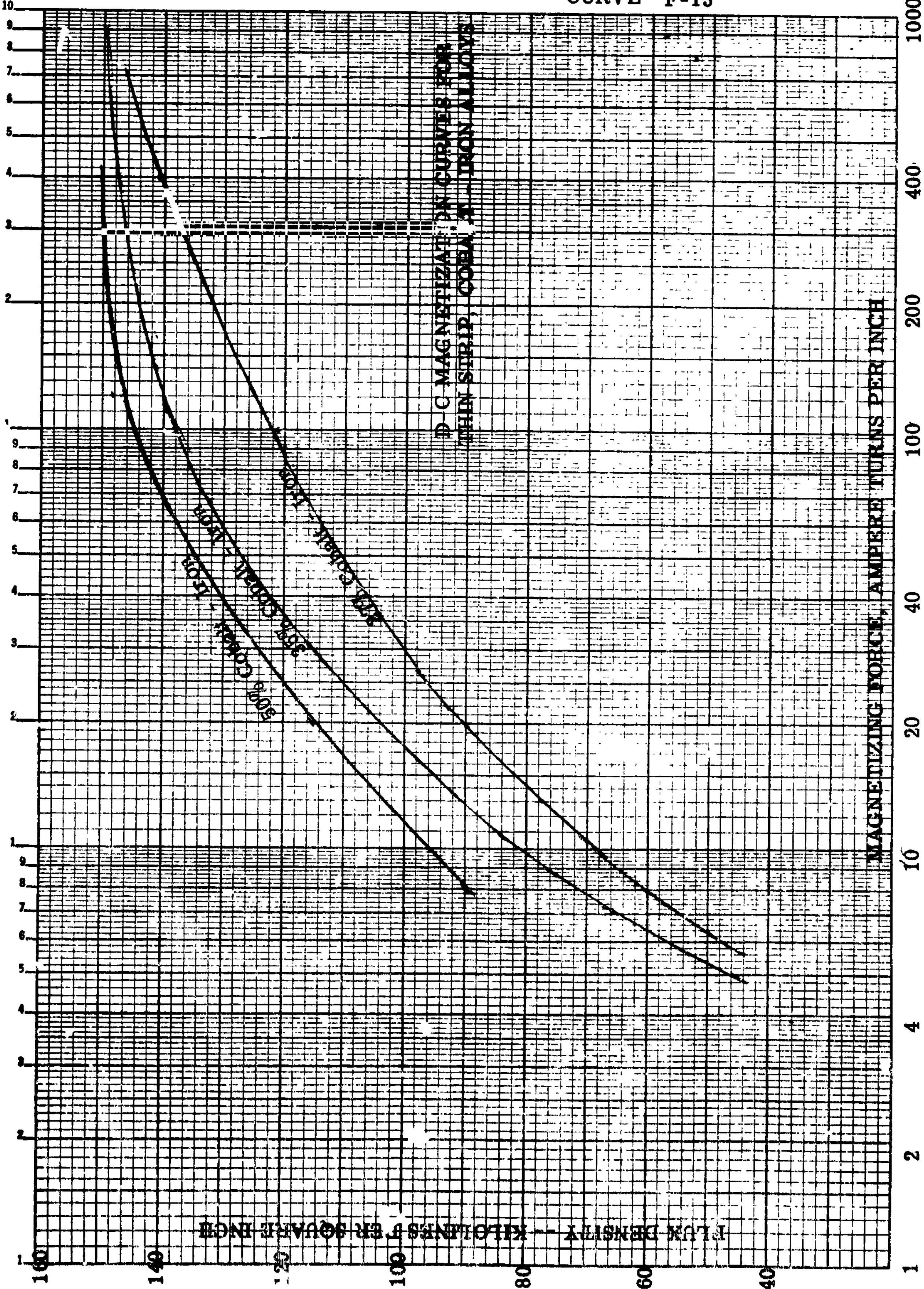
CURVE F-11 h
CORE LOSS VERSUS FREQUENCY FOR THREE GRADES OF SILICON STEEL AT 77.4 KL/IN2 FLUX DENSITY



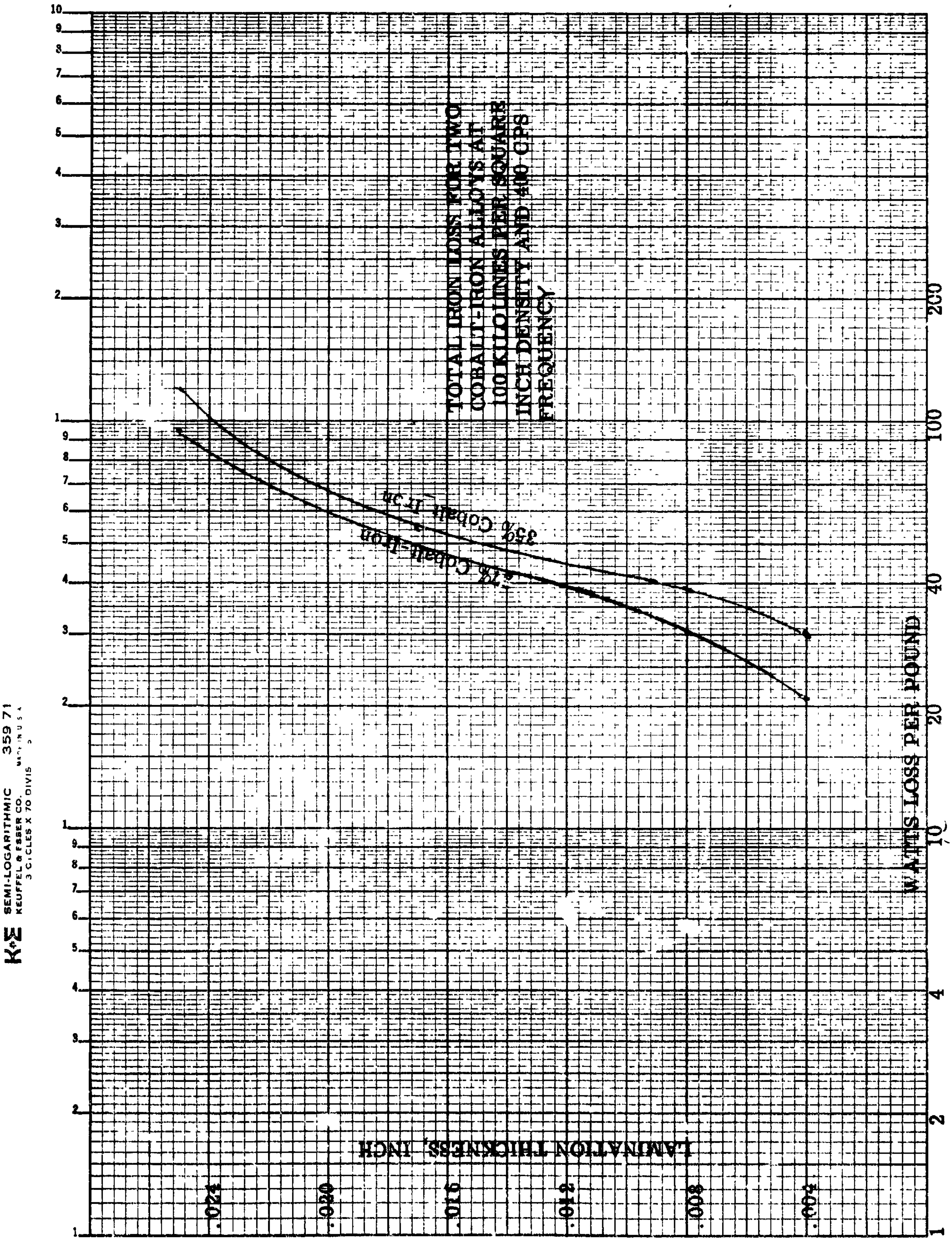
CURVE F-12


AISI 1006
1008
1010
As received
1% max. carbon
Kilolines per square inch
0
20
40
60
80
100
120
140
1
2
4
6
8
10
20
40
60
80
100
200
400
600
1000

CURVE F-13

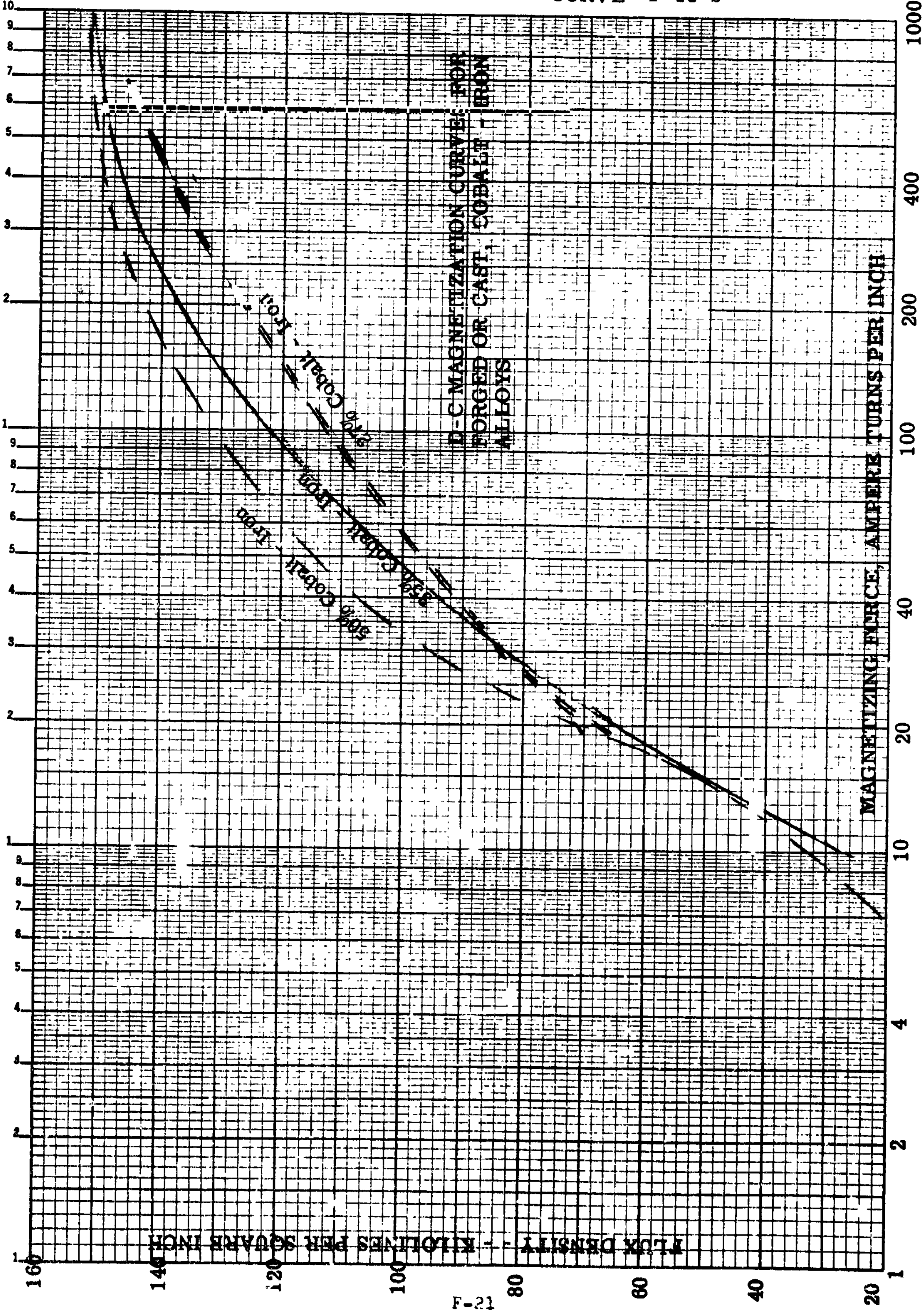

D C MAGNETIZATION CURVES FOR THIN STRIP, COBALT - IRON ALLOYS
MAGNETIZING FORCE, AMPERE TURNS PER INCH
FLUX DENSITY -- KILOLINES PER SQUARE INCH
50% Cobalt - Iron
35% Cobalt - Iron
1000
400
200
100
40
20
10
4
2
1
160
140
120
100
80
60
40

CURVE F-13 a



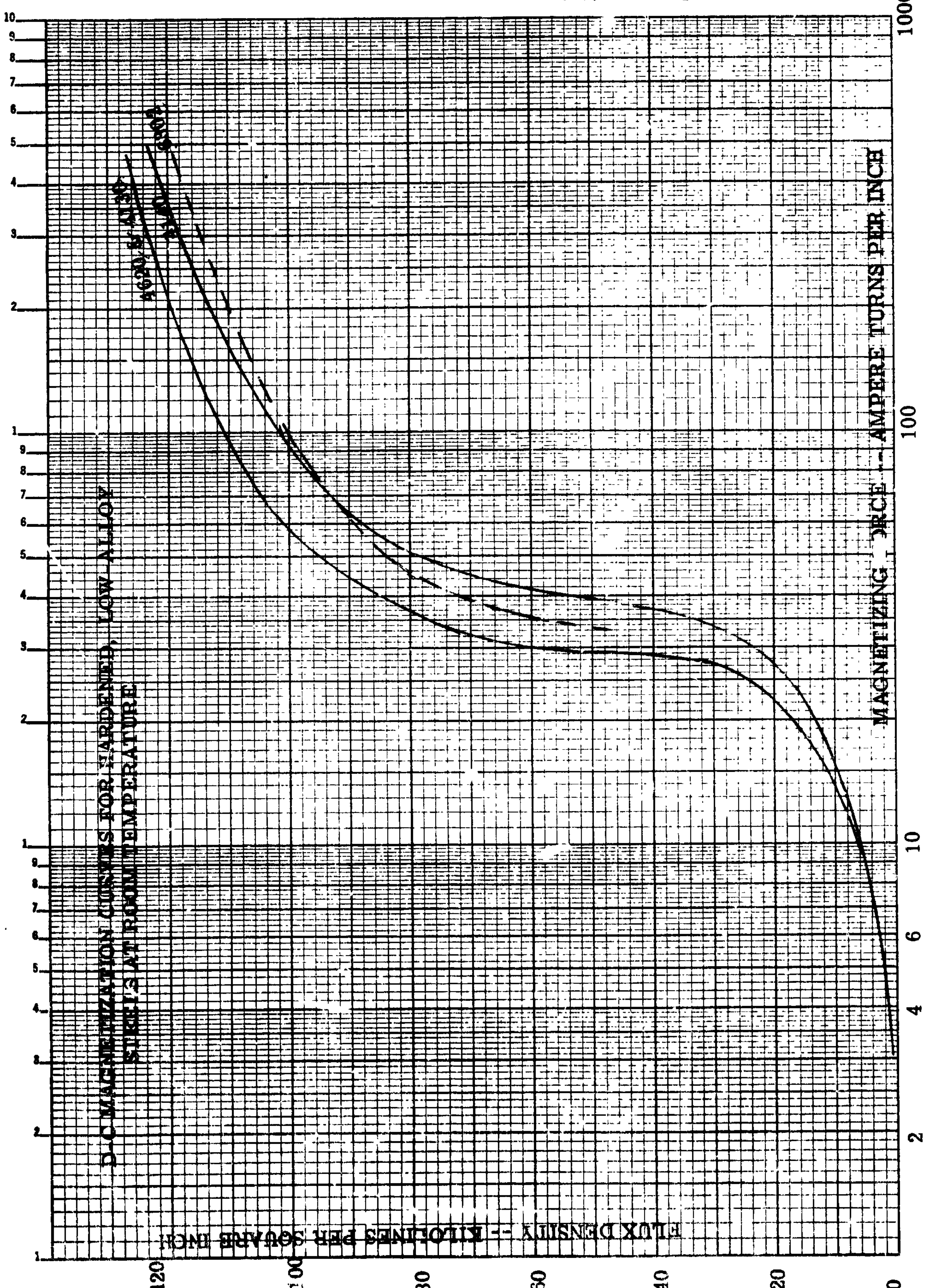
TOTAL IRON LOSS FOR TWO COBALT-IRON ALLOYS AT 100 KILOLINES PER SQUARE INCH DENSITY AND 400 CPS FREQUENCY
35% Cobalt-Iron
WATTS LOSS PER POUND
LAMINATION THICKNESS, INCH
.024
.020
.016
.012
.008
.004
200
100
40
20
10
4
2
1

CURVE F-13 b



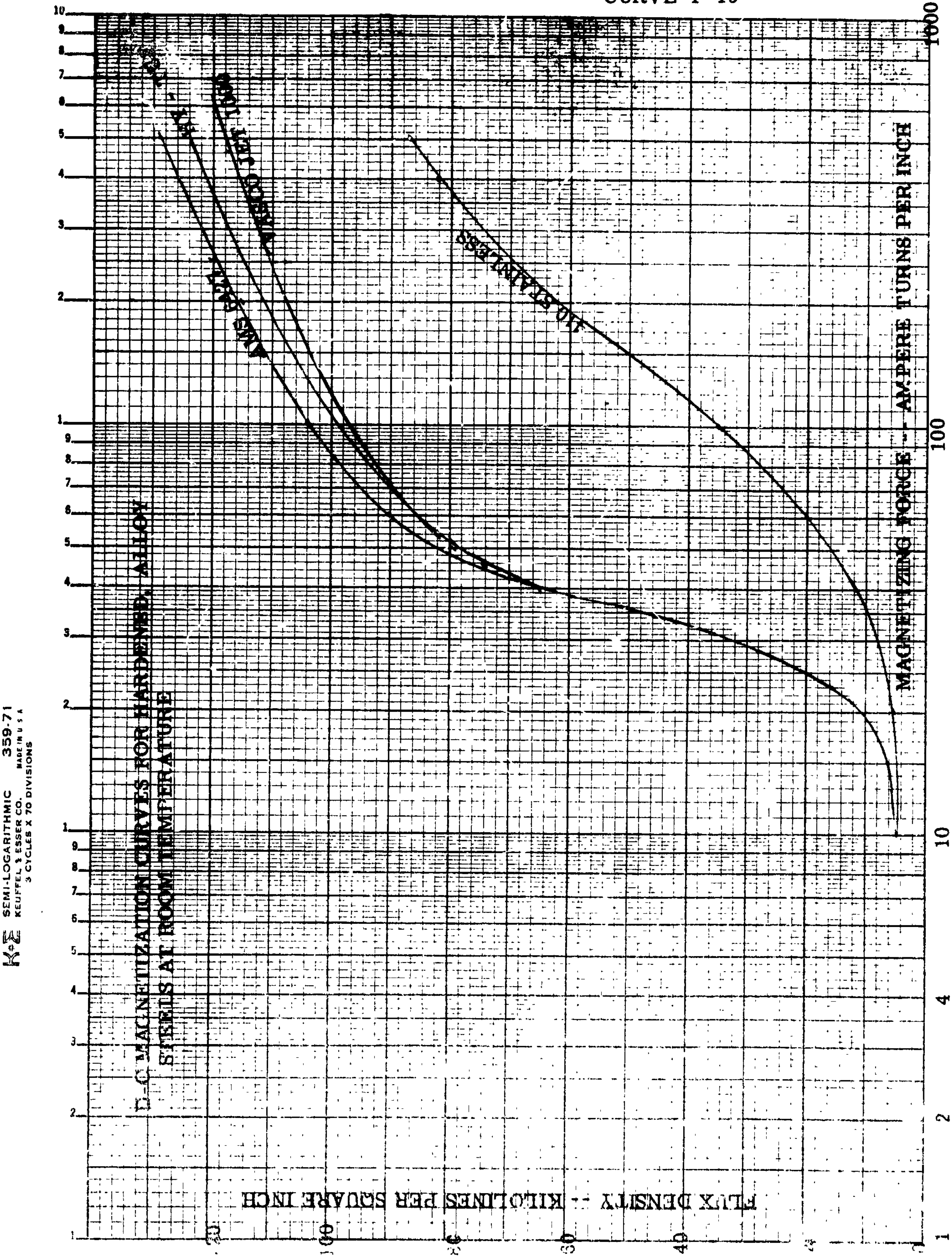
K+E SEMI-LOGARITHMIC 359-71
3 CYCLES X 70 DIVISIONS

CURVE F-14



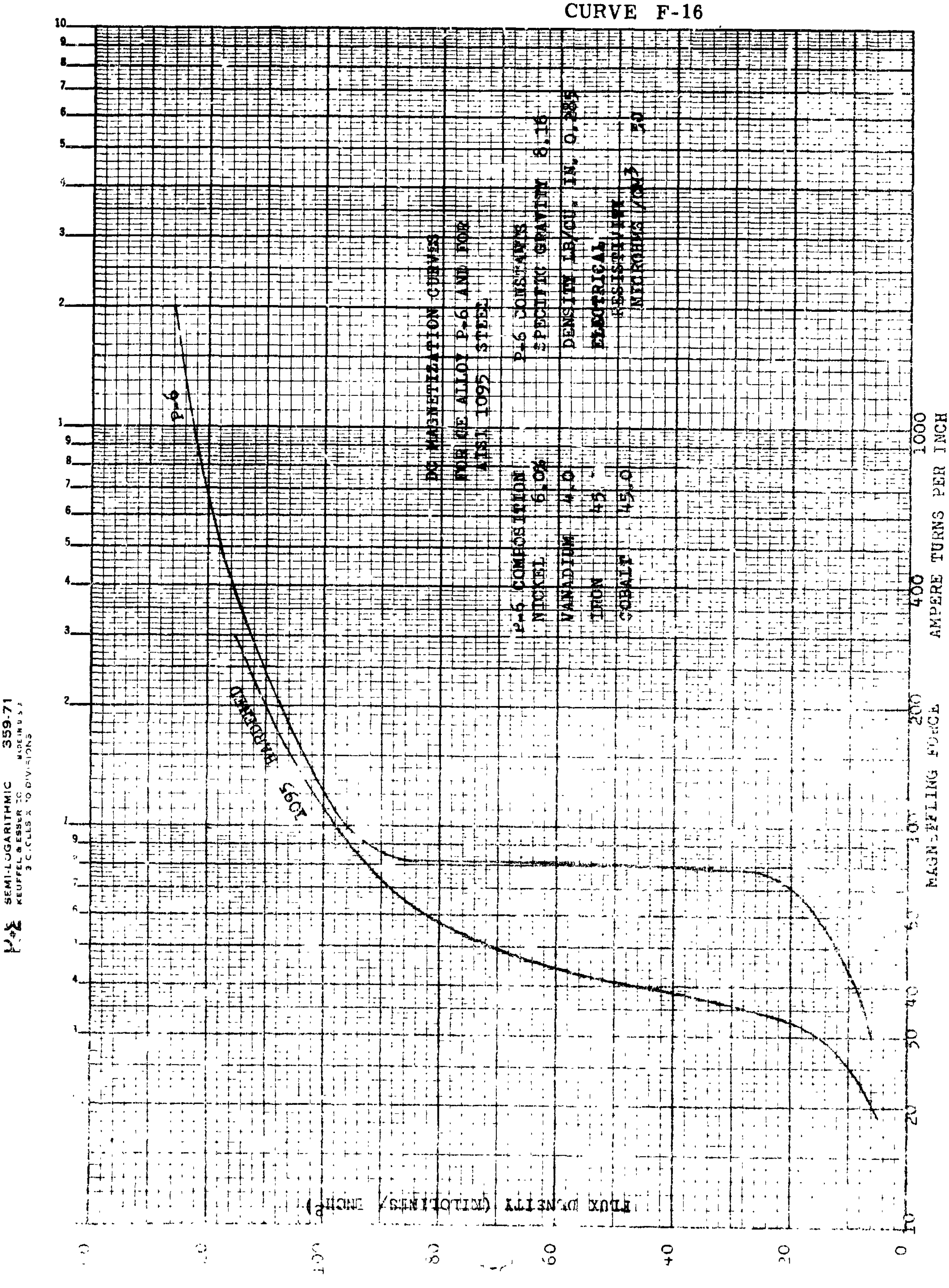
D-C MAGNETIZATION CURVES FOR HARDENED, LOW ALLOY
STEELS AT ROOM TEMPERATURE
4620 & 4130
4140
6150
MAGNETIZING FORCE -- AMPERE TURNS PER INCH
FLUX DENSITY -- KILOLINES PER SQUARE INCH
1000
100
10
6
4
2
120
100
80
60
40
20
0
K+E SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS

CURVE F-15



D-C MAGNETIZATION CURVES FOR HARDENED, ALLOY
STEELS AT ROOM TEMPERATURE
MAGNETIZING FORCE -- AMPERE TURNS PER INCH
FLUX DENSITY -- KILOLINES PER SQUARE INCH
410 STAINLESS
SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS

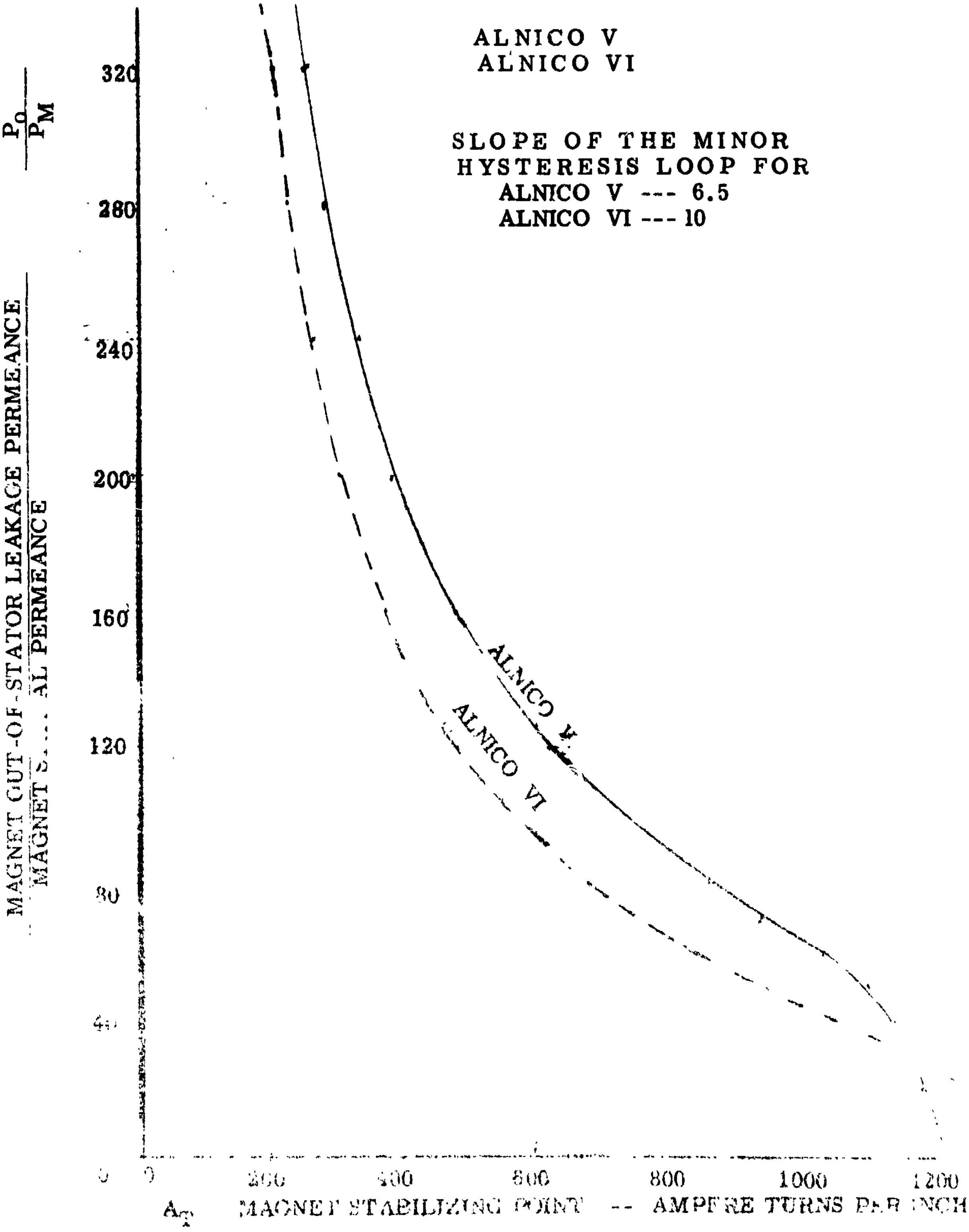
CURVE F-16



DC MAGNETIZATION CURVES
FOR GE ALLOY P-6 AND FOR
AISI 1095 STEEL
P-6 CONSTANTS
SPECIFIC GRAVITY 8.16
DENSITY LB/CU. IN.
ELECTRICAL
P-6 COMPOSITION
NICKEL 6.0%
VANADIUM 4.0
IRON 45
COBALT 45.0
P-6
HARDENED
1095
AMPERE TURNS PER INCH
MAGNETIZING FORCE
FLUX DENSITY (KILOLINES/ INCH^2)

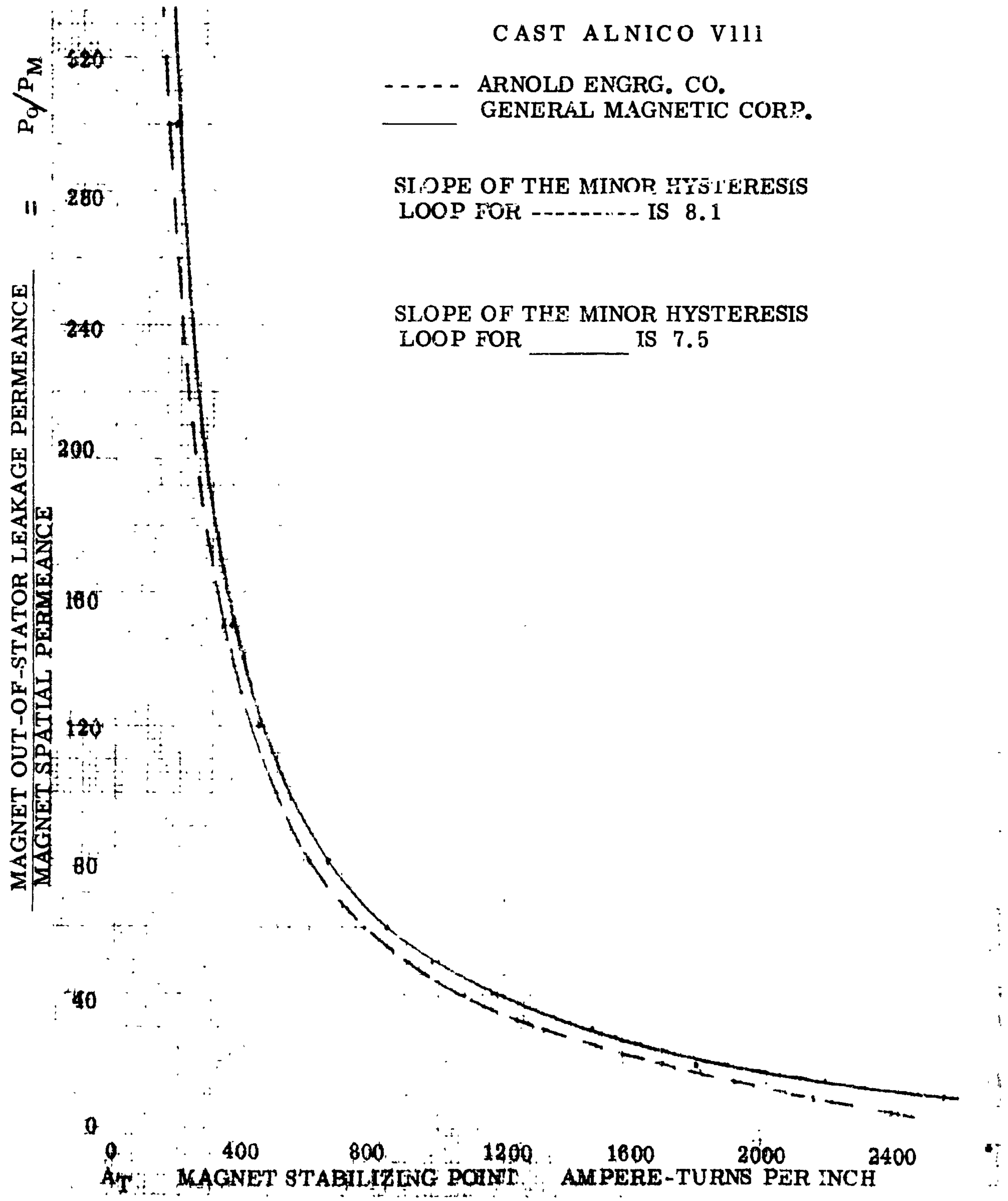
CURVE F-17

MAGNET STABILIZATION POINT (A_T) VERSUS THE OUT-OF-STATOR LEAKAGE PERMEANCE



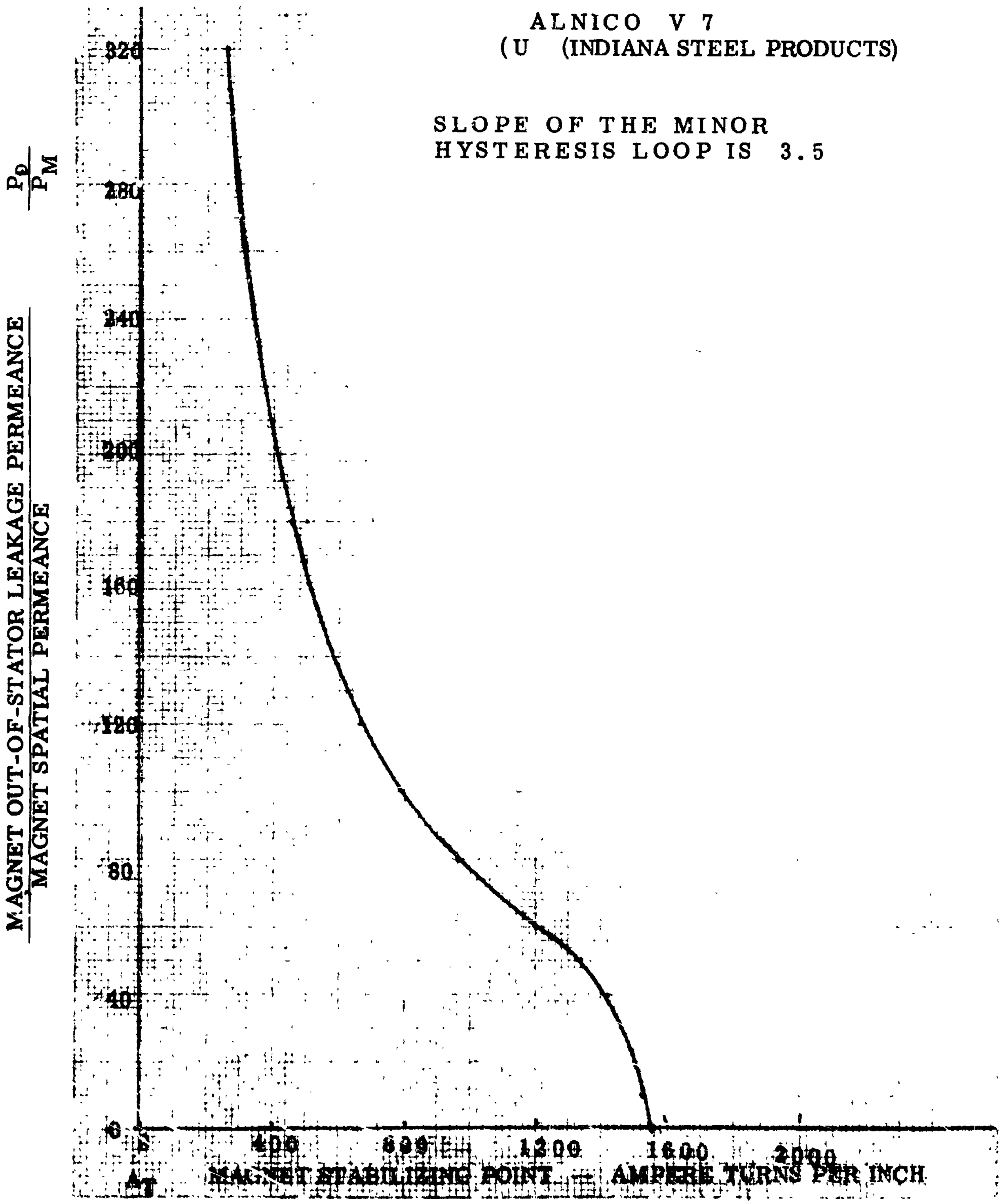
CURVE F-18

(A_T)
MAGNET STABILIZATION POINT VERSUS
OUT-OF-STATOR LEAKAGE PERMEANCE



CURVE F-19

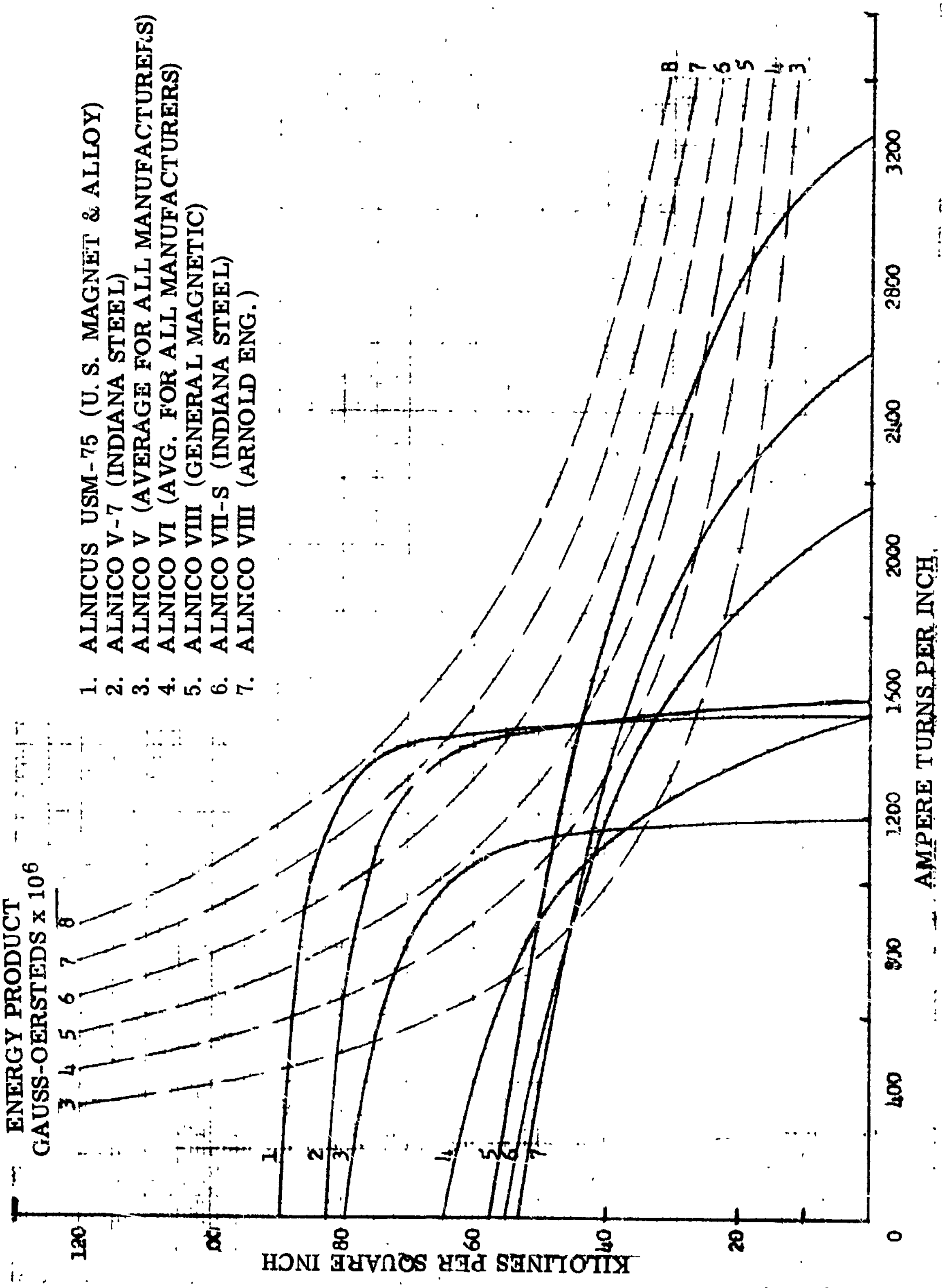
MAGNET STABILIZATION POINT (A_T) VERSUS OUT-OF-STATOR LEAKAGE PERMEANCE



DEMAGNETIZATION CURVES FOR HIGH ENERGY PRODUCT CAST ALNICOS

1-2-63

CURVE F-20



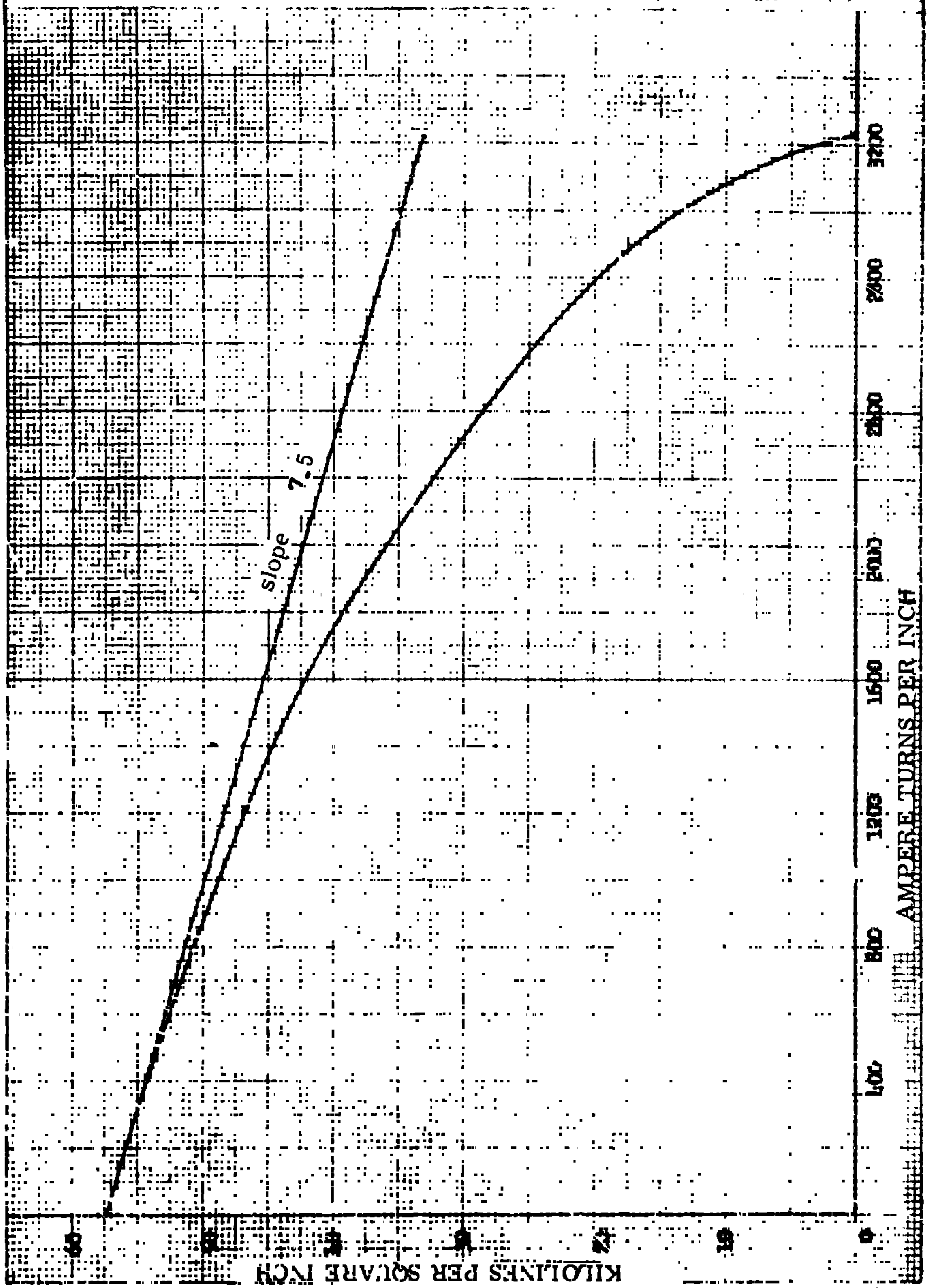
TJS

SHOWING

DEMAGNETIZATION CURVE FOR CAST ALNICO VIII
(GENERAL MAGNETIC CORP.)

CURVE F-21

DATE 12-19-62

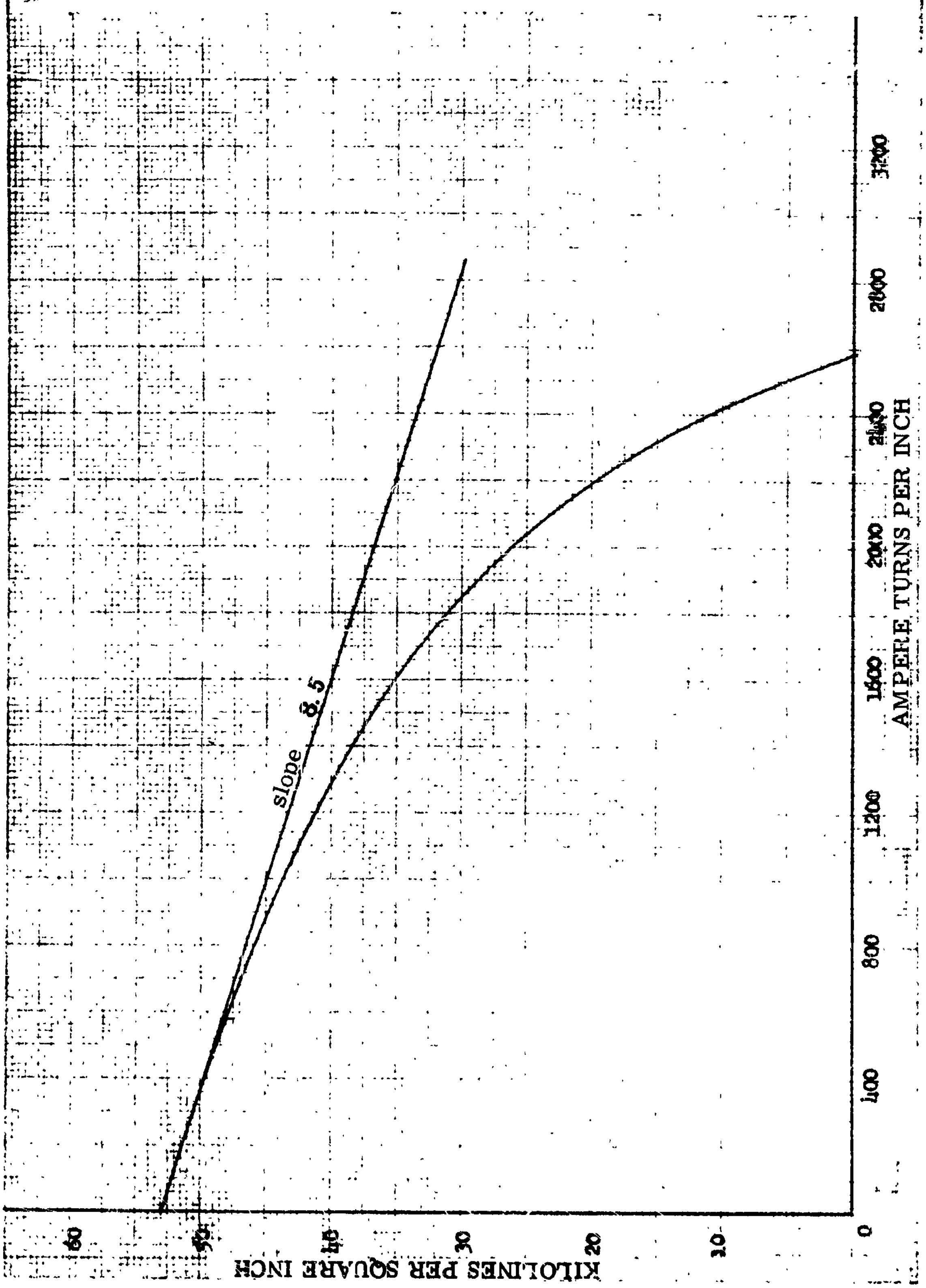


TJS

DEMAGNETIZATION CURVE FOR CAST ALNICO VIII
(ARNOLD ENGINEERING CO.)

CURVE F-22

12-19-62

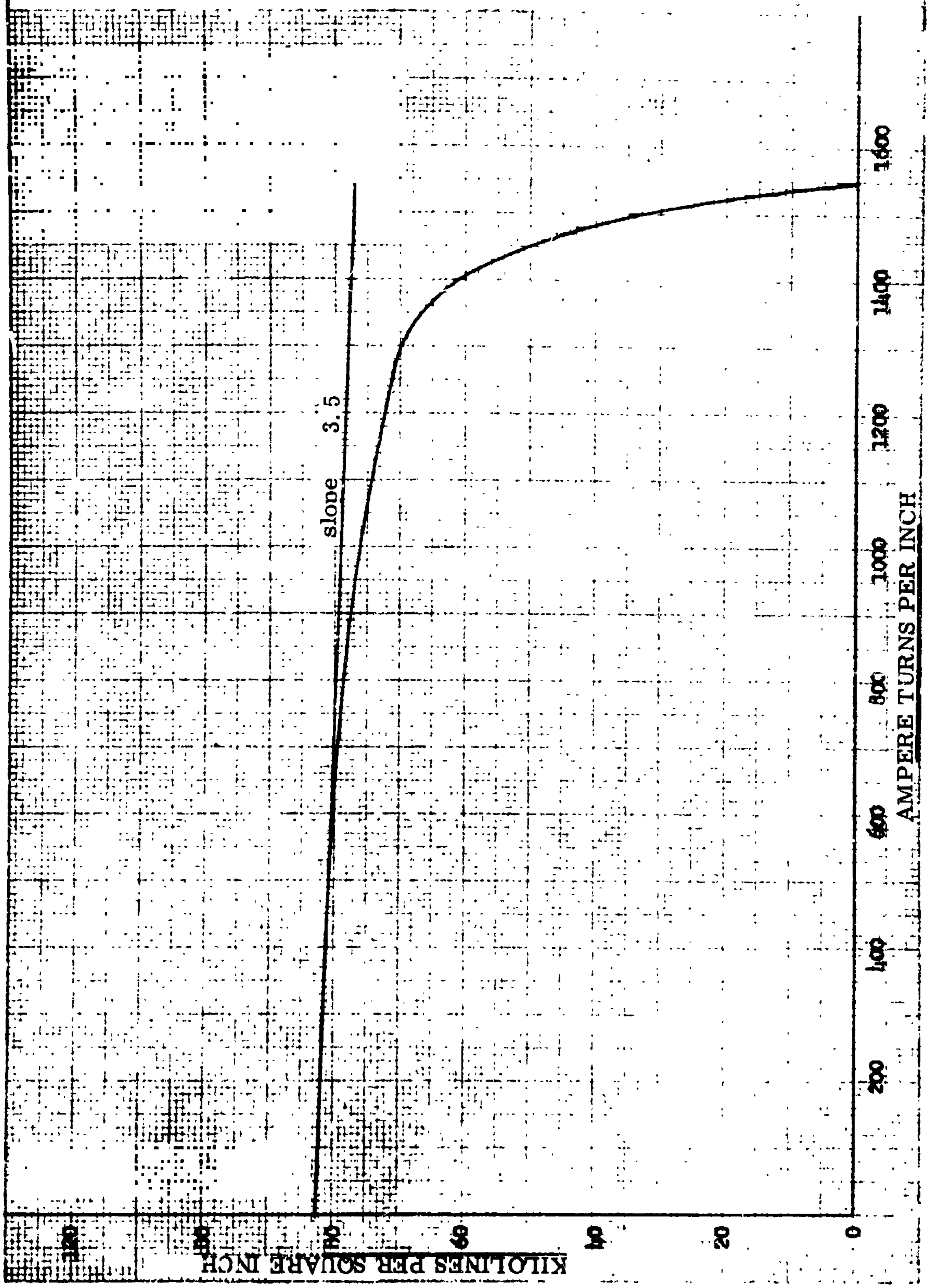


SHOWING

DEMAGNETIZATION CURVE FOR CAST ALNICO V-7
(INDIANA STEEL PRODUCTS)

CURVE F-23

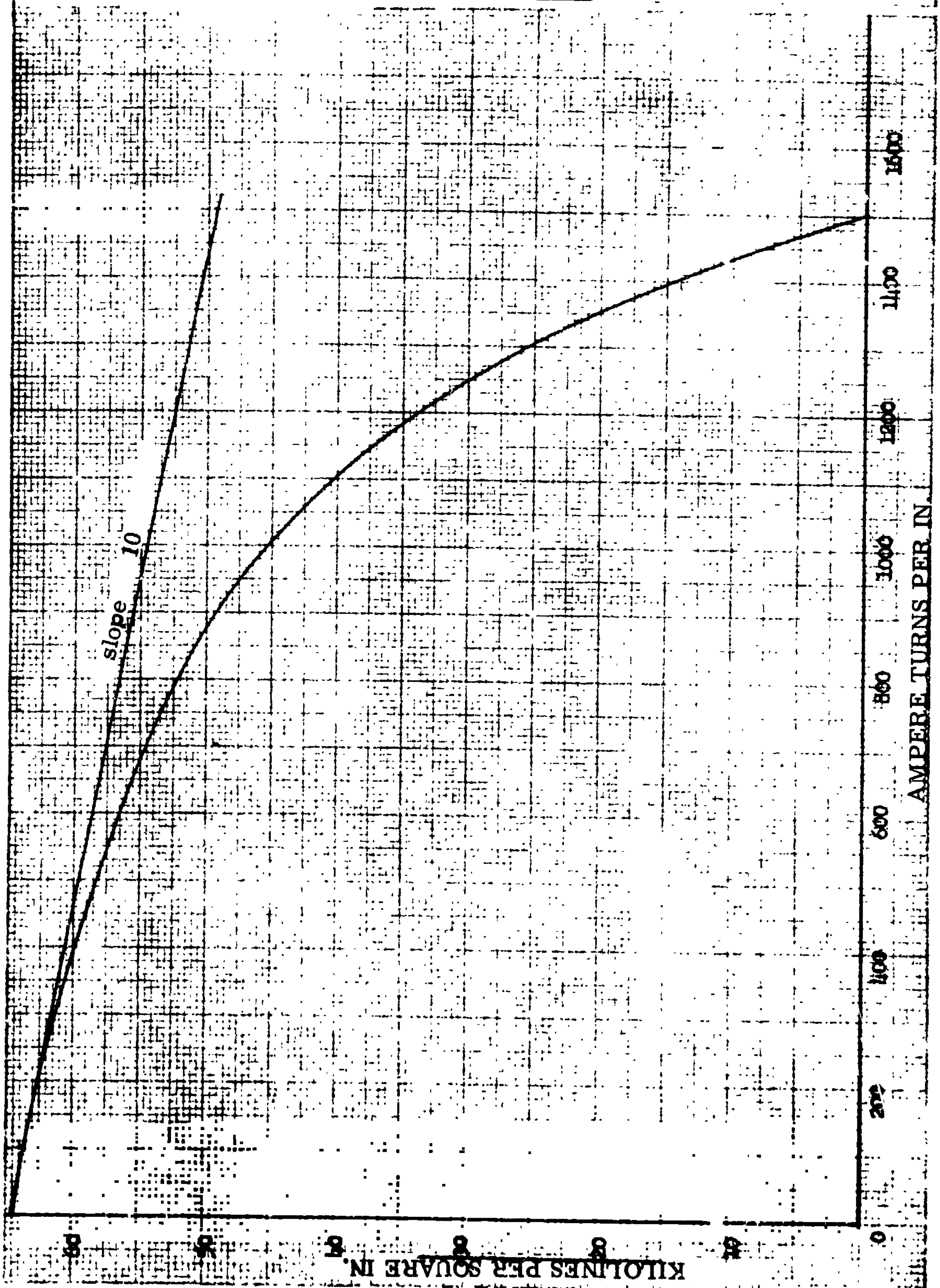
DATE 12-19-62



12-19-62

DEMAGNETIZATION CURVE FOR CAST ALNICO VI
(AVG. FOR ALL MANUFACTURERS)

CURVE F-24

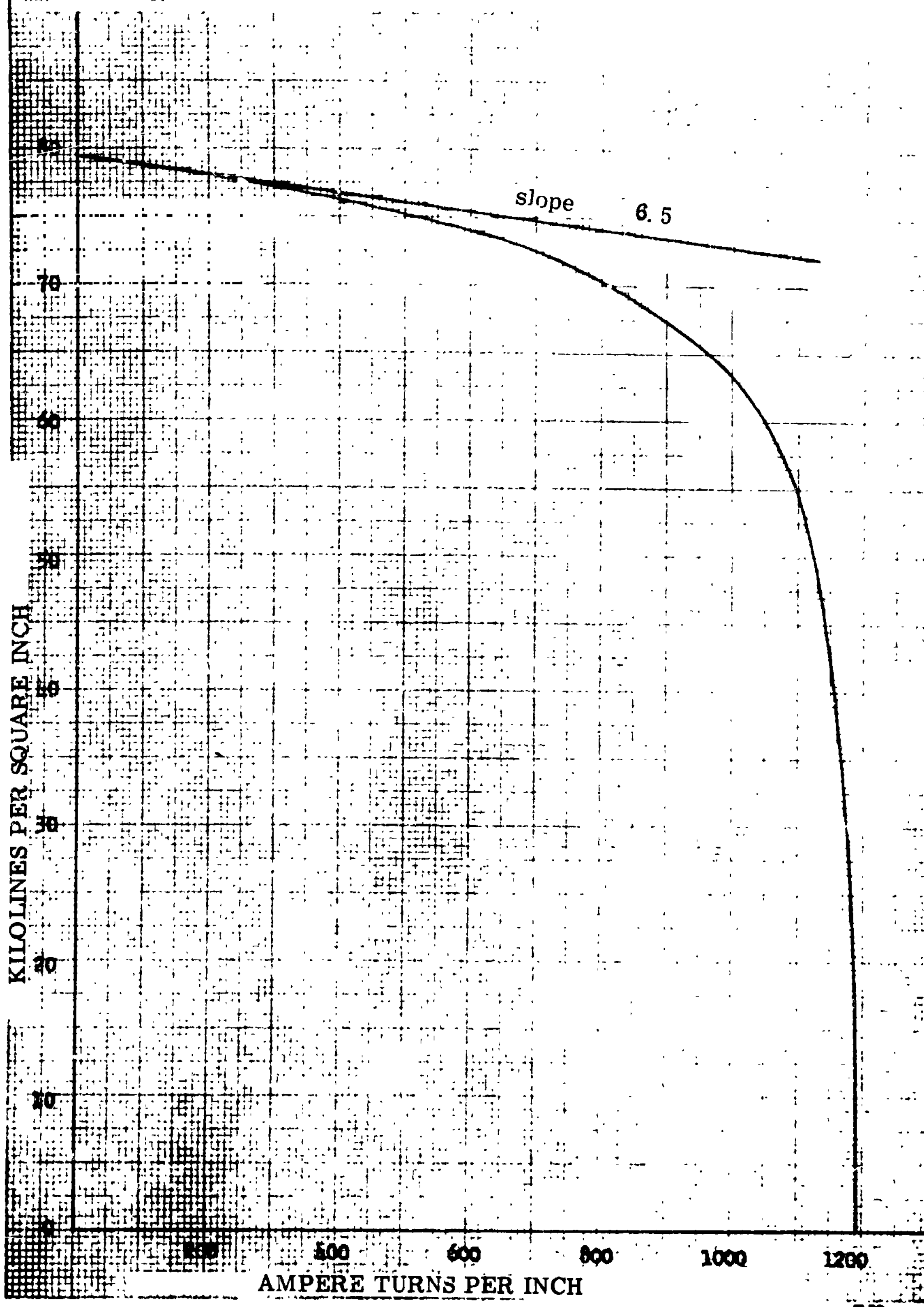


TJS

12-19-62

DEMAGNETIZATION CURVE FOR CAST ALNICO V
(AVG. FOR ALL MANUFACTURERS)

CURVE F-25



TJS

CURIE POINTS OF THE MAGNETIC MATERIALS

USED IN GENERATORS, MOTORS AND INDUCTORS

Material	Curie Point °C
Iron	770
Cobalt	1130
Nickel	358
50 Co 3 Mn 47 Fe (Permendur)	980
49 Co 2 V 49 Fe (2 V Permendur)	980
35 Co 5 Cr 6 Mn .7 Ni 63 Fe	960
27 Co 5 Cr 6 Mn .7 Ni 71 Fe	940
Silicon-Iron 2 Si	756
Silicon-Iron 8 Si	720
Silicon-Iron 11 Si	690
65 Permalloy 65 Ni - Iron	620
79 Ni Permalloy	580
7-70 Perminvar 70 Ni 7 Co - Fe	650
Perminvar 45 Ni 25 Co - Fe	720
Perminvar 45 Ni 25 Co 7.5 Mo - Fe	535
78 Ni 4 Mo - Fe (P-Alloy)	460
79 Ni 5 Mo - Fe (Supermalloy)	400
47 Ni 3 Mo - Fe (Nonimax)	510
43 Ni 3.25 Si - Fe (Sinimax)	510
76 Ni 1.5 Cr 4 Cu - Fe (Mu-Metal)	450

CURIE POINTS OF THE MAGNETIC MATERIALS

USED IN GENERATORS, MOTORS AND INDUCTORS

(Continued)

Material	Curie Point °C
36 Ni - Fe (Invar)	275
42 Ni - Fe	400
50 Ni - Fe (Deltamax)	510
15 AL 3.3 Mo - Fe (Thermenol)	400
Alnico 5 - 24 Co 14 Ni 8 AL 3 Cu	880
Alnico 6 - 24 Co 15 Ni 8 AL 3 Cu 1.25 Ti	880
Chrome Steel .9 C .3 Mn 3.5 Cr	745
3% Cobalt Steel 1.0 C 3 Co 4 Cr .4 Mo	804
17% Cobalt Steel .8 C 17 Co 25 Cr 8 W	840
36% Cobalt Steel .7 C 36 Co 4 Cr 5 W	890

MAGNETIC PROPERTIES OF Cr Ni STEELS

AISI Type No.	% Cr	% Ni	% Cold Reduction	Magnetic Permeability H = 50 Oersteds	Magnetic Permeability H = 200 Oersteds	Tensile Strength Lb/Sq. In.
Special	19.2	8.4	0	1.0042	1.0048	89,100
			8.3	1.128	1.136	120,400
			16.7	5.70	6.23	138,200
			27.8	13.6	14.1	156,000
			48.0	49.0	33.4	202,000
301	17.6	7.8	0	1.0027	1.0028	95,000
			19.5	1.148	1.257	140,600
			55.0	14.8	19.0	222,400
302	18.4	9.0	0	1.0025	1.0035	95,300
			20.0	1.0076	1.011	130,200
			44.0	1.050	1.120	171,000
			68.0	1.59	2.70	214,000
			84.0	2.15	6.65	236,000
304	19.0	10.7	0	1.0037	1.0040	81,000
			13.8	1.0048	1.0060	101,100
			32.0	1.0371	1.062	145,900
			65.0	1.540	2.12	180,400
			84.5	2.20	4.75	202,800
308	17.9	11.7	0	1.0032	1.0044	88,200
			18.5	1.0040	1.0054	129,100
			34.5	1.017	1.020	154,700
			52.5	1.049	1.063	175,900
			84.0	1.093	1.142	197,800
310	24.3	20.7	0	1.0018	1.0035	107,800
			14.7	1.0016	1.0041	128,100
			26.8	1.0018	1.0043	155,000
			64.2	1.0019	1.0041	192,600
316 2.4% MO.	17.5	13.4	0	1.0030	1.0040	83,600
			20.8	1.0030	1.0043	117,800
			45.0	1.0040	1.0065	159,900
			60.8	1.0065	1.0072	178,000
			81	1.0070	1.0100	194,100

MAGNETIC PROPERTIES OF Cr Ni STEELS (Cont)

AISI Type No.	% Cr	% Ni	% Cold Reduction	Magnetic Permeability H = 50 Oersteds	H = 200 Oersteds	Tensile Strength Lb/Sq. In.
321						
0.68% Ti	18.3	10.3	0	1.0033	1.0035	87,800
			16.5	1.018	1.023	123,200
			41.5	1.40	1.61	162,200
			53.5	2.44	3.34	174,400
			70.5	6.76	9.40	201,300
347						
0.95% Cb.	18.4	10.7	0	1.0037	1.0044	94,800
			13.5	1.0074	1.0085	118,200
			40.0	1.062	1.088	166,100
			60.0	1.245	1.445	179,300
			90.0	1.97	4.12	216,500

Ref: Heat treatment and physical properties of the Austenitic Chromium - Ni Steels - International Nickel Co. Bulletin

NON-MAGNETIC STEELS

The Chrome-Nickel steels of the 300 series are used as non-magnetic spacers and support members in rotor weldments, braces and other structural locations where it is desirable to use a material with a permeability of one (1).

Some of the 300 series steels are non-magnetic in the "soft" condition but when they are work hardened part of the steel changes phase and becomes magnetic. The 18-8 steel (see 301 on chart) becomes useless for non-magnetic needs when cold reduced 25% to 50%.

INPUT AUXILIARY DATA SHEET

Auxiliary information taken from the design manuals to be used in conjunction with input sheets for convenience.

A. All dimensions for lengths, widths, and diameters are to be given in inches.

B. Resistivity inputs, Items (141) and (151) are to be given in micro-ohm-inches.

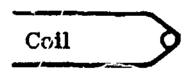
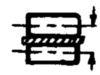
The following items along with an explanation of each are tabulated here for convenience. For complete explanation of each item number, refer to design manuals.

Item No.	Explanation
(9)	Power factor to be given in per unit. For example for 90% P.F., insert .90.
(9a)	Adjustment Factor - For P.F. $<$.95 insert 1.0 For P.F. $>$ .95 insert 1.05
(10)	Optional Load Point -- Where load data output is required at a point other than those given as standard on the input sheet. Example: For load data output at 155% load, insert 1.55.
(14)	Number of radial ducts in stator.
(15)	Width of radial ducts used in Item (14).
(18)	Magnetization curve of material used to be submitted as defined in Item (18).
(19)	Watts/Lb. to be taken from a core loss curve at the density given in Item (20) (Stator).
(20)	Density in kilolines/in^2. This value must correspond to density used to pick Item (19) usually use 77.4 KL/in^2.
(21)	Type of slot - For open slot Type A, insert 1.0. For partially open slot Type B with constant slot width, insert 2.0. For partially open slot Type C with constant tooth width, insert 3.0. For round slot Type D, insert 4.0. For additional information, refer to figure adjacent to input sheet which shows a picture of each slot.
(22)	For stator slot dimension - for dimensions that do not apply to the slot insert 0.0. Use Table below as guide for input.

Symbol	Item	Slot Type 1	2	3	4
b_o	(22)	0.0	*	*	*
b_1	↓	0.0	0.0	*	0.0
b_2		0.0	0.0	*	0.0
b_3		0.0	0.0	*	0.0
b_s		*	*	φ	*
h_o		0.0	*	*	*
h_1		*	*	*	0.0
h_2		*	0.0	0.0	0.0
h_3		*	*	0.0	0.0
h_s		*	*	*	*
h_t		0.0	*	*	0.0
h_w	↓	0.0	*	*	0.0

* = insert actual value.

$$\varphi = b_s = \frac{b_1 + b_3}{2}$$

Item No.	Explanation
(28)	Type of winding - for wye connected winding insert 1.0.
	for delta connected winding insert 0.0.
(29)	Type of coil - for formed wound (rect. wire), insert 1.0.
	for random wound (round wire) insert 0.0.
(30)	Slots spanned - Example - for slot span of 1-10, insert 9.0.
(33)	For round wire insert diameter. For rectangular wire insert wire width.
(34)	Strands per conductor in depth only.
(34a)	Total strands per conductor in depth and width.
(35)	Diameter of coil head forming pin. Insert .25 for stator O.D. < 8 inches; Insert .50 for stator O.D. > 8 in. 
(37)	Use vertical height of strand for round wire, insert 0.0.
(38)	Distance between centerline of strands in depth. Insulation  h'st
(39)	Stator strand thickness -- use narrowest dimension of the two dimensions given for a rectangular wire. For round wire insert 0.0.
(40)	Stator slot skew in inches.
(42a)	Phase belt angle - for 60° phase belt, insert 60°.
	for 120° phase belt, insert 120°.
(48)	See explanation of items (71), (72), (73), (74) and (75). Same applies here.
(87)	When no load saturation output data is required at various voltages, insert 1.0.
	When no load saturation information is not required, insert 0.0.
(137)	Damper bar thickness -- use damper bar slot height for rectangular bar. For round bar insert 0.0.
(138)	Number of damper bars per pole.
(140)	Damper bar pitch in inches.
(148)	For round wire insert diameter. For rectangular wire insert wire width.
(149)	For rectangular wire insert wire thickness. For round wire insert 0.0.
(187)	Pole face loss factor. For rotor lamination thickness .028 in. or less, insert [illegible]
	For rotor lamination thickness .029 in. to .063 in. insert 1.75.
	For rotor lamination thickness .064 in. to .125 insert 3.5.
	For solid rotor insert 7.0.
(71) (72) (73) (74) (75)	If the values of these constants are available, insert the actual number. If they are not available, insert 0.0 and the computer will calculate the values and record them on the output.

SALIENT POLE COMPUTER DESIGN (INPUT)

MODEL ______________________ EWO __________ DESIGN NO(1) ____________________

Group	No.	Symbol	Item		
PARAMETERS	(2)	KVA	GENERATOR KVA		
	(3)	E	LINE VOLTS		
	(4)	E_{ph}	PHASE VOLTS		
	(5)	m	PHASES		
	(5a)	f	FREQUENCY		
	(6)	p	POLES		
	(7)	RPM	RPM		
	(8)	I_{ph}	PHASE CURRENT		
	(9)	PF	POWER FACTOR		
	(9a)	K_c	ADJ. FACTOR		
	(10)		OPTIONAL LOAD POINT		
STATOR STACK	(11)	d	STATOR I.D.		
	(12)	D	STATOR O.D.		
	(13)	ℓ	GROSS CORE LENGTH		
	(14)	n_v	NO. OF DUCTS		
	(15)	b_v	WIDTH OF DUCT		
	(16)	K_I	STACKING FACTOR (STATOR)		
	(19)	k	WATTS/LB.		
	(20)	B	DENSITY		
STATOR SLOT	(21)		TYPE OF SLOT		
	(22)	b_o	SLOT OPENING		
	(22)	b_1	SLOT WIDTH TOP		
	(22)	b_2			
	(22)	b_3			
	(22)	b_s	SLOT WIDTH		
	(22)	h_o			
	(22)	h_1			
	(22)	h_2			
	(22)	h_3			
	(22)	h_s	SLOT DEPTH		
	(22)	h_t			
	(22)	h_w			
	[illegible]	Q	NO. OF SLOTS		
STATOR WINDING	(28)		TYPE OF WDG.		
	(29)		TYPE OF COIL		
	(30)	n_s	CONDUCTORS/SLOT		
	(31)	y	SLOTS SPANNED		
	(32)	c	PARALLEL CIRCUITS		
	[illegible]		STRAND DIA. OR WIDTH		
	[illegible]	N_{st}	STRANDS/CONDUCTOR		
	[illegible]	N'_{st}	STRANDS/CONDUCTOR		
	[illegible]		STATOR STRAND T'KNS		
	[illegible]	d_b	DIA. OF PIN		
	(36)	ℓ_{e2}	COIL EXT. STR. PORT		
	(37)	h_{st}	UNINS. STRD. HT.		
	[illegible]	h'_{st}	DIST. BTWN. C_L OF STD.		
	[illegible]		PHASE BELT/ANGLE		
	[illegible]	τ_{sk}	STATOR SLOT SKEW		
	(50)	X_s °C	STATOR TEMP ° C		
	(51)	ρ_s	RES'TVY STA. COND. @ 20° C		
GAP	(39)	g_{min}	MINIMUM AIR GAP		
	(39a)	g_{max}	MAXIMUM AIR GAP		

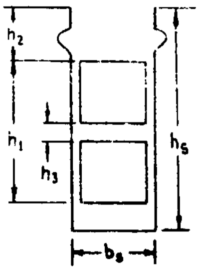
	Item	No.	Symbol	Group
	FUND/MAX OF FIELD FLUX	(71)	C_1	CONSTANTS
	WINDING CONSTANT	(72)	C_w	
	POLE CONST.	(73)	C_p	
	END EXTENSION ONE TURN	(48)	L_E	
	DEMAGNETIZATION FACTOR	(74)	C_m	
	CROSS MAGNETIZING FACTOR	(75)	C_q	
	POLE HEAD WIDTH	(76)	b_h	ROTOR STACK
	POLE BODY WIDTH	(76)	b_p	
	POLE HEAD HEIGHT	(76)	h_h	
	POLE BODY HEIGHT	(76)	h_f	
	POLE BODY LENGTH	(76)	ℓ_p	
	POLE HEAD LENGTH	(76)	ℓ_n	
	POLE EMBRACE	(77)	α	
	ROTOR DIAMETER	(11a)	d_r	
	STACKING FACTOR (ROTOR)	(16)	K_I	
	WEIGHT OF ROTOR IRON	(157)	(-)	
	POLE FACE LOSS FACTOR	(187)	(K_1)	
	WIDTH OF SLOT OPENING	(135)	b_{bo}	DAMPER BAR
	HEIGHT OF SLOT OPENING	(135)	h_{bo}	
	DAMPER BAR DIA. OR WIDTH	(136)	( )	
	RECTANGULAR BAR THICKNESS	(137)	h_{bl}	
	RECTANGULAR SLOT WIDTH	(135)	b_{bl}	
	NO. OF DAMPER BARS	(138)	n_b	
	DAMPER BAR LENGTH	(139)	ℓ_b	
	DAMPER BAR PITCH	(140)	τ_b	
	RESISTIVITY OF DAMP. BAR @ 20°	(141)	ρ_b	
	DAMPER BAR TEMP ° C	(142)	X_p ° C	
	NO. OF FIELD TURNS	(146a)	N_p	FIELD
	MEAN LENGTH OF FLD. TURN	(147)	ℓ_{tr}	
	FLD. COND. DIA. OR WIDTH	(148)		
	FLD. COND. THICKNESS	(149)		
	FLD. TEMP IN ° C	(150)	X_f ° C	
	RESISTIVITY OF FIELD COND @ 20°	(151)	ρ_f	
	NO LOAD SAT.	(87)		
	FRICTION & WINDAGE	(183)	(F&W)	
	ROTOR LAM. MTR'L	(18)		MATR'L
	STATOR LAM. MTR'L (CURVE)	(18)		

STATOR SLOT	POLE
DAMPER SLOT	REMARKS

DESIGNER ____________________ DATE __________

REV. A

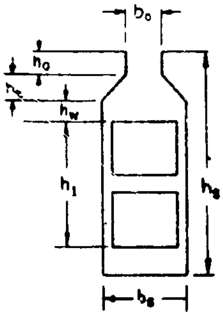
(a) Open Slots



TYPE 1

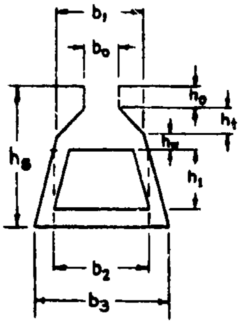
(Type 5 is an open slot with 1 conductor per slot)

(b) Constant Slot Width



TYPE 2

(c) Constant Tooth Width

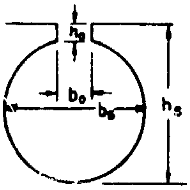


TYPE 3

b_s for type 3 is

$$b_s = \left(\frac{b_2 + b_3}{2}\right)$$

(d) Round Slots



TYPE 4

SUMMARY OF DESIGN CALCULATIONS – SALIENT POLE (OUTPUT)

MODEL ______________________ EWO __________ DESIGN NO. ____________________

STATOR	(17) (ℓ_s)	SOLID CORE LENGTH			CARTER COEFFICIENT	(67) (K_s)	GAP
	(24) (h_c)	DEPTH BELOW SLOT			AIR GAP AREA	(68) (-)	
	(26) (τ_s)	SLOT PITCH			AIR GAP PERM	(70c) (λ_a)	
	(27) (τ_s 1/3)	SLOT PITCH 1/3 DIST. UP			EFFECTIVE AIR GAP	(69) (g_e)	
	(42) (K_{sk})	SKEW FACTOR			FUND/MAX OF FLD. FLUX	(71) (C_1)	CONSTANTS
	(43) (K_d)	DIST. FACTOR			WINDING CONST.	(72) (C_w)	
	(44) (K_p)	PITCH FACTOR			POLE CONST.	(73) (C_p)	
	(45) (n_e)	EFF. CONDUCTORS			END. EXT. ONE TURN	(48) (L_E)	
	(46) (a_c)	COND. AREA			DEMAGNETIZING FACTOR	(74) (C_M)	
	(47) (S_s)	CURRENT DENSITY (STA.)			CROSS MAGNETIZING FACTOR	(75) (C_q)	
	(49) (ℓ_t)	1/2 MEAN TURN LENGTH			AMP COND/IN	(128) (A)	REACTANCE
	(53) (R_{ph})	COLD STA. RES. – 20° C			REACTANCE FACTOR	(129) (X)	
	(54) (R_{ph})	HOT STA. RES – X° C			LEAKAGE REACTANCE	(130) (X_ℓ)	
	(55) (EF_{top})	EDDY FACTOR TOP			REACTANCE OF	(131) (X_{ad})	
	(56) (EF_{bot})	EDDY FACTOR BOT			ARMATURE REACTION	(132) (X_{aq})	
	(62) (λ_i)	STATOR COND. PERM.			SYN REACT DIRECT AXIS	(133) (X_d)	
	(64) (λ_e)	END PERM.			SYN REACT QUAD AXIS	(134) (X_q)	
	(65) ( )	WT. OF STA COPPER			FIELD LEAKAGE REACT	(160) (X_f)	
	(66) ( )	WT. OF STA IRON			FIELD SELF INDUCTANCE	(161) (L_f)	
ROTOR	(41) (τ_p)	POLE PITCH			DAMPER	(163) (X_{Dd})	
	(79) (a_p)	POLE AREA			LEAKAGE REACT	(165) (X_{Dq})	
	(82b) ($\lambda_{e\ell}$)	POLE END LEAK PERM.			UNSAT. TRANS. REACT	(166) (X'_{du})	
	(81b) ($\lambda_{t\ell}$)	POLE TIP LEAK PERM.			SAT. TRANS. REACT	(167) (X'_d)	
	(80b) ($\lambda_{s\ell}$)	POLE SIDE LEAK PERM.			SUB.TRANS.REACT DIRECT AX.	(168) (X''_d)	
	(153) (a_{CF})	FLD. COND. AREA			SUB.TRANS.REACT QUAD AX.	(169) (X''_q)	
	(154) (R_F)	COLD FLD RES – 20° C			NEG SEQUENCE REACT	(170) (X_2)	
	(155) (R_F)	HOT FLD RES – X C			ZERO SEQUENCE REACT	(172) (X_o)	
	(156) ( )	WT OF FLD COPPER			TOTAL FLUX	(88) (ϕ_t)	MAGNETIZATION
	(157) ( )	WT OF ROTOR IRON			FLUX PER POLE	(92) (ϕ_p)	
	(145) (V_r)	PERIPHERAL SPEED			GAP DENSITY	(95) (B_g)	
TIME CONSTANTS	(176) (T_{do})	OPEN CIR. TIME CONST.			TOOTH DENSITY	(91) (B_t)	
	(177) (T_a)	ARM TIME CONST.			CORE DENSITY	(94) (B_c)	
	(178) (T'_d)	TRANS TIME CONST.			TOOTH AMPERE TURNS	(97) (F_t)	
	(179) (T''_d)	SUB TRANS TIME CONST.			CORE AMPERE TURNS	(98) (F_c)	
	(180) (F_{sc})	SHORT CIR NI			GAP AMPERE TURNS	(96) (F_g)	
	(181) (SCR)	SHORT CIR RATIO					

PERCENT LOAD	0		100	150	200	OPTIONAL
VARIABLE LOAD (ϕ_ℓ) (100a) LEAK FLUX		(ϕ_ℓ) (197a)				
(ϕ_{pt}) (102a) POLE FLUX		(ϕ_{pt}) (213a)				
(B_p) (103a) POLE DENSITY		(B_p) (213b)				
(F_p) (104a) POLE NI		(F_{pt}) (213c)				
(F_{nl}) (127) TOTAL NI		(F_R) (2[illegible])				
(I_{nl}) (127a) FIELD AMPS		(I_{fl}) (237)				
(S_F) (127c) CUR.DENS.(FLD)		(S_{fl}) (239)				
(E_F) (12[illegible]) FIELD VOLTS		(E_{fl}) (238)				
(I^2R_f) (182) ROTOR LOSS		(I^2R_f) (241)				
(F&W) (183) F&W LOSS		(F&W) (183)				
(W_{mt}) (184) STA TOOTH LOSS		(W_{mt}) (242)				
(W_c) (185) STA CORE LOSS		(W_c) (185)				
(W_{pnl}) (186) POLE FACE LOSS		(W_{pfl}) (243)				
(W_{dnl}) (193) DAMPER LOSS		(W_{dfl}) (244)				
(I^2R_s) (194) STATOR CU LOSS		(I^2R_s) (245)				
(–) (195) EDDY LOSS		(–) (246)				
(–) (196) TOTAL LOSSES		(–) (247)				
(–) (–) RATING (KW)		(–) (248)				
(–) (–) RATING & LOSSES		(–) (249)				
(–) (–) PERCENT LOSSES		(–) (250)				
(–) (–) PERCENT EFF.		(–) (251)				

REMARKS

G-03

DESIGNER

DATE

REV A

NO LOAD SATURATION OUTPUT SHEET

ITEMS / VOLTS	(3) (E) VOLTS / (98a) (F_s) STATOR A.T.	(96) (F_g) AIR GAP A.T. / (100a) (ϕ) LEAKAGE FLUX	(91) (B_t) TOOTH DENSITY / (102a) (ϕ_p) TOTAL FLUX/POLE	(97) (F_t) TOOTH A.T. / (103A) (B_p) POLE DENSITY	(94) (B_c) CORE DENSITY / (104a) (F_p) POLE A.T.	(98) (F_c) / (127) (F_{nl}) TOTAL A.T. (N.L.)
80%						
90%						
100%						
110%						
120%						
130%						
140%						
150%						
160%						

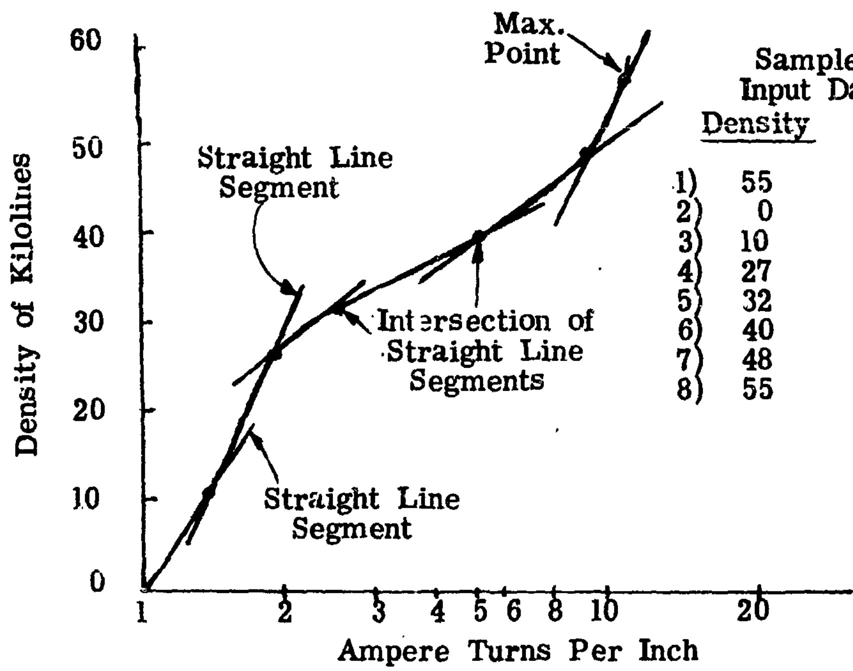
(1)	--	DESIGN NUMBER - To be used for filing purposes
(2)	KVA	GENERATOR KVA
(3)	E	LINE VOLTS
(4)	E_{PH}	PHASE VOLTS - For 3 phase, wye connected generator $E_{PH} = \frac{\text{(Line Volts)}}{\sqrt{3}} = \frac{(3)}{\sqrt{3}}$ For 3 phase, delta connected generator $E_{PH} = \text{(Line Volts)} = (3)$
(5)	m	PHASES - Number of
(5a)	f	FREQUENCY - In cycles per second
(6)	P	POLES - Number of
(7)	RPM	SPEED - In revolutions per minute
(8)	I_{PH}	PHASE CURRENT - In amperes at rated load
(9)	P.F.	POWER FACTOR - Given in per unit
(9a)	K_c	ADJUSTMENT FACTOR - When P.F. = 0. to .95 set $K_c = 1.$; when P.F. = .95 to 1. set $K_c = 1.05$
(10)	--	LOAD POINTS - The computer program has standard outputs for 0, 100%, 150%, 200% load points plus one optional load point that can be any value between 0 and 2 p.u. If no optional calculation is desired, insert 0.0 for item (10) on the input sheet.

(11)	d	STATOR PUNCHING I.D. - The inside diameter of the stator punching in inches
(11a)	d_r	ROTOR PUNCHING O.D. - The outside diameter of the rotor punching in inches
(12)	D	PUNCHING O.D. - The outside diameter of the stator punching in inches
(13)	ℓ	GROSS CORE LENGTH - In inches
(14)	n_v	RADIAL DUCTS - Number of
(15)	b_v	RADIAL DUCT WIDTH - In inches
(16)	K_i	STACKING FACTOR - This factor allows for the coating (core plating) on the punchings, the burrs due to slotting, and the deviations in flatness. Approximate values of K_i are given below.

THICKNESS OF LAMINATIONS (INCHES)	GAGE	K_i
.014	29	0.92
.018	26	0.93
.025	24	0.95
.028	23	0.97
.063	--	0.98
.125	--	0.99

(17)	ℓ_s	SOLID CORE LENGTH - The solid length is the gross length times the stacking factor. If ventilating ducts are used, their length must be subtracted from the gross length also. $$\ell_s = (K_i)\left[(\ell) - (n_v)(b_v)\right] = (16)\left[(13) - (14)(15)\right]$$
(18)	--	LAMINATION MATERIAL - This input is used in selecting the proper magnetization curves for the stator and rotor material. Where curves are available on card decks, use the proper identifying code. Where card decks are not available submit data in the following manner: The magnetization curve must be available on semi-log paper. Typical curves are shown in Section F on Curve F15. Draw straight line segments through the curve starting with zero density. Record the coordinates of the points where the straight line segments intersect. Submit these coordinates as input data for the magnetization curve. The maximum density point must be submitted first.

Refer to Figure below for complete sample



Sample Input Data

	Density	NI
1)	55	Max.
2)	0	0
3)	10	1.5
4)	27	1.9
5)	32	2.5
6)	40	4.9
7)	48	9.0
8)	55	12.0

(19) k **WATTS/LB** - Core loss per lb of stator lamination material.

Must be given at the frequency specified. Curve F-11a provides losses at 400 cps and 77.4 kilolines/in^2.

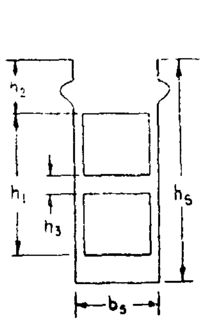
(20) B **DENSITY** - This value must correspond to the density used in Item (19) to pick the watts/lb. The density that is usually used is 77.4 kilolines/in^2.

(21) | 1 | **TYPE OF STATOR SLOT** - Designate the type of slot from the following figure.
2
3 For (a) slot use 1. as an input
4 For (b) slot use 2. as an input
5 For (c) slot use 3. as an input

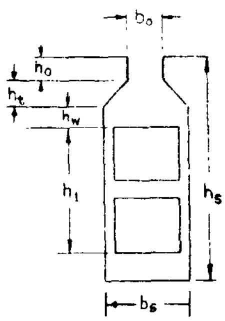
For (d) slot use 4. as an input

Type 5. is not a slot but instead a particular situation for an open slot where the winding has only one conductor per slot.

(a) Open Slots



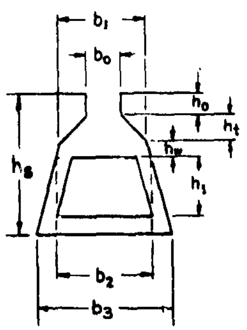
(b) Constant Slot Width



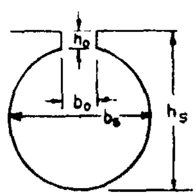
*Note: For slot type C,

$$b_s = \frac{(b_1) + (b_3)}{2}$$

*(c) Constant Tooth Width



(d) Round Slots



(22)	b_0, b_1, b_2, b_3, b_s, h_0, h_1, h_2, h_3, h_s, h_t, h_w	ALL SLOT DIMENSIONS - Given in inches per item(21). Where the dimension does not apply to the slot being used, insert 0. on input sheet. For slot type C $b_s = \frac{(b_1) + (b_3)}{2} = \frac{(22) + (22)}{2}$
(23)	Q	STATOR SLOTS - Number of
(24)	h_c	DEPTH BELOW SLOTS - The depth of the stator core below the slots. (in inches) Due to mechanical strength reasons, h_c should never be less than 70% of h_s. $h_c = \frac{(D) - \left[(d) + 2(h_s)\right]}{2} = \frac{(12) - \left[(11) + 2(22)\right]}{2}$
(25)	q	SLOTS PER POLE PER PHASE $q = \frac{(Q)}{(P)(m)} = \frac{(23)}{(6)(5)}$
(26)	τ_s	STATOR SLOT PITCH, inches $\tau_s = \frac{\pi(d)}{Q} = \frac{\pi(11)}{(23)}$

(27)	$\tau_{s1/3}$	STATOR SLOT PITCH - 1/3 distance up from narrowest section For slot (a), (b), (c), and (e) --(in inches) $$\tau_{s1/3} = \frac{\pi\left[(d) + .66(h_s)\right]}{(Q)} \quad \frac{\pi\left[(11) + .66(22)\right]}{(23)}$$ For slot (d) $$\tau_{s\ 1/3} = \frac{\pi\left[(d) + 2(h_0) + 1.32(b_s)\right]}{(Q)}$$ $$= \frac{\pi\left[(11) + 2(22) + 1.32(22)\right]}{(23)}$$
(28)	--	TYPE OF WINDING - Record whether the connection is "wye" or "delta". For "wye" conn use 1. for input. For "delta" use 0. for input
(29)	--	TYPE OF COIL - Record whether random wound or formed coils are used. For random wound coils use 0. for input. For formed coils use 1. for input.
(30)	n_s	CONDUCTORS PER SLOT - The actual number of conductors per slot. For random wound coils use a space factor of 75% to 80%. Where space factor is the percent of the total slot area that is available for insulated conductors after all other insulation areas have been subtracted out.
(31)	y	THROW - Number of slots spanned. For example, with a coil side in slot 1 and the other coil side in slot 10, the throw is 9.

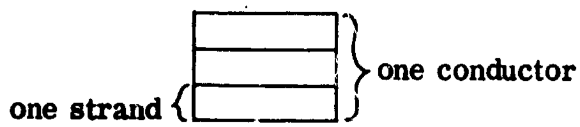
(31a) | | **PER UNIT OF POLE PITCH SPANNED** - Ratio of the number of slots spanned to the number of slots in a pole pitch. This value must be between 1.0 and 0.5 to satisfy the limits of this program.

$$= \frac{(Y)}{(m)\ (q)} = \frac{(31)}{(5)\ (25)}$$

(32) | C | **PARALLEL PATHS**, No. of - Number of parallel circuits per phase.

(33) | -- | **STRAND DIA. OR WIDTH** - In inches. For round wire, use strand diameter. For rectangular wire, use strand width. This must be the largest of the two dimensions given for a rectangular wire.

(34) | N_{ST} | **NUMBER OF STRANDS PER CONDUCTOR IN DEPTH** - Applies to rectangular wire. To reduce eddy current loss a stranded conductor is often used. For example, when the space available for one conductor is .250 width x .250 depth, the actual conductor can be made up of 2 or 3 strands in depth as shown. For round wire insert 1.0



(34a)	N'_{ST}	NUMBER OF STRANDS PER CONDUCTOR - This number applies to the strands in depth and/or width and is used in calculating the conductor area. Item (34) is different in that it deals with strands in depth only and is used in calculating eddy factors.
(35)	d_b	DIAMETER OF BENDER PIN - in inches - This pin is used in forming coils. Use .25 inch for stator O.D. < 8 inches use .50 inches for stator O.D. > 8 inches.
(36)	ℓ_{e2}	COIL EXTENSION BEYOND CORE in Inches - Straight portion of coil that extends beyond stator core.
(37)	h_{ST}	HEIGHT OF UNINSULATED STRAND in Inches - This value is the vertical height of the strand and is used in eddy factor calculations. Set this value = 0 for round wire.
(38)	h'_{ST}	DISTANCE BETWEEN CENTERLINES OF STRANDS IN DEPTH in inches.
(39)	--	STATOR COIL STRAND THICKNESS in inches - For rectangular conductors only. For round wire insert 0. on input sheet. This must be the narrowest dimension of the two dimensions given for a rectangular wire.
(40)	τ_{SK}	SKEW - Stator slot skew in inches at stator I.D.

(41)	τ_P	POLE PITCH in inches. $$\tau_p = \frac{\pi(d)}{(P)} = \frac{\pi(11)}{(6)}$$
(42)	K_{SK}	SKEW FACTOR - The skew factor is the ratio of the voltage induced in the coils to the voltage that would be induced if there were no skew. When $\tau_{SK} = 0$, $K_{SK} = 1$ $$K_{SK} = \frac{\sin\left[\frac{\pi(\tau_{SK})}{2(\tau_P)}\right]}{\frac{\pi(\tau_{SK})}{2(\tau_P)}} = \frac{\sin\left[\frac{\pi(40)}{2(41)}\right]}{\frac{\pi(40)}{2(41)}}$$
(42a)		PHASE BELT ANGLE - Input. For phase belt angle = 60° insert 60 on input sheet. For phase belt angle = 120° insert 120 on input sheet.
(43)	K_d	DISTRIBUTION FACTOR - The distribution factor is the ratio of the voltage induced in the coils to the voltage that would be induced if the windings were concentrated in a single slot. See Table F-2 for compilation of distribution factors for the various harmonics.

(44) K_P

PITCH FACTOR - The ratio of the voltage induced in the coil to the voltage that would be induced in a full pitched coil. See Table F-1 for compilation of the pitch factors for the various harmonics.

$$K_P = \sin\left[\frac{(Y)}{(m)(q)} \times 90^{\circ}\right] = \sin\left[\frac{(31)}{(5)(25)} \times 90^{\circ}\right]$$

(45) n_e

TOTAL EFFECTIVE CONDUCTORS - The actual number of effective series conductors in the stator winding taking into account the pitch and skew factors but not allowing for the distribution factor.

$$n_e = \frac{(Q)(n_s)(K_P)(K_{SK})}{(C)} = \frac{(23)(30)(44)(42)}{(32)}$$

(46) a_c

CONDUCTOR AREA OF STATOR WINDING in $(\text{inches})^2$ - The actual area of the conductor taking into account the corner radius on square and rectangular wire. See the following table for typical values of corner radii

If (39) = 0 then $a_c = .25\pi(\text{Dia})^2 = .25\pi(33)^2$

If (39) $\neq$ 0 then $a_c = (N'_{ST})\left[(\text{strand width})(\text{strand depth}) - (.858\ r_c^2)\right] = (34a)\left[(33)(39) - (.858\ r_c^2)\right]$

where $.858\ r_c^2$ is obtained from Table below.

(39)	(33) .188	.189 (33) .75	(33) .751
.050	.000124	.000124	.000124
.072	.000210	.000124	.000124
.125	.000210	.00084	.000124
.165	.000840	.00084	.003350
.225	.001890	.00189	.003350
.438	--	.00335	.007540
.688	--	.00754	.01340
--	--	.03020	.03020

For 60^o phase belt angle and q = integer when (42a) = 60 and (25) = integer.

$$K_d = \frac{\text{Sin } 30^o}{(q) \text{ Sin}\left[30/(q)\right]} = \frac{\text{Sin } 30^o}{(25) \text{ Sin}\left[30/(25)\right]}$$

For 60^o phase belt angle and (q) $\neq$ integer = N/B reduced to lowest terms.

When (43a) = 60 and (25) $\neq$ integer = N/B reduced to lowest terms

$$K_d = \frac{\text{Sin } 30^o}{(N) \text{ Sin}\left[30/(N)\right]} = \frac{\text{Sin } 30^o}{(43) \text{ Sin}\left[30/(43)\right]}$$

For 120^o phase belt angle and (q) = integer

When (43a) = 120 and (25) = integer

$$K_d = \frac{\text{Sin } 60^o}{2(q) \text{ Sin}\left[30/(q)\right]} = \frac{\text{Sin } 60^o}{2(25) \text{ Sin}\left[30/(25)\right]}$$

For 120^o phase belt angle and q $\neq$ integer

When (43a) = 120 and (25) $\neq$ integer = N/B reduced to lowest terms

$$K_d = \frac{\text{Sin } 60^o}{2(N) \text{ Sin}\left[30/(N)\right]} = \frac{\text{Sin } 60^o}{2(43) \text{ Sin}\left[30/(43)\right]}$$

(47) S_S CURRENT DENSITY - Amperes per square inch of stator conductor

$$S_S = \frac{(i_{PH})}{(C)(a_c)} = \frac{(8)}{(32)(46)}$$

(48) L_E END EXTENSION LENGTH in inches - Can be an input or output.

For L_E to be output, insert 0. on input sheet.

For L_E to be input, calculate per following:

When (29) = 0 then:

$$L_E = \frac{.5 + K_T \pi y \boxed{d + h_S}}{Q} = .5 + \frac{\begin{bmatrix} 1.3 \text{ If } (6) = 2 \\ 1.5 \text{ If } (6) = 4 \\ 1.7 \text{ If } (6) > 4 \end{bmatrix} \pi (31) \boxed{(11) + (22)}}{(23)}$$

When (29) = 1. then:

$$L_E = 2(\ell_{e2}) + \pi \left[\frac{h_1}{2} + (d_b)\right] + y \left[\frac{\tau_s^2}{\sqrt{\tau_s^2 - b_s^2}}\right]$$

$$= 2 \times (36) + \pi \left[\frac{(22)}{2} + (35)\right] + (31) \left[\frac{(26)^2}{\sqrt{(26)^2 - (22)^2}}\right]$$

(49) ℓ_t 1/2 MEAN TURN - The average length of one conductor in inches

$$\ell_t = (\ell) + (L_E) = (13) + (48)$$

(50) $X_S\,^\circ C$ STATOR TEMP $^\circ$C. - Input temp at which F.L. losses will be calculated. No load losses and cold resistance will be calculated at 20°C.

(51)	ρ_s	**RESISTIVITY OF STATOR WINDING** - In micro ohm-inches @ 20°C. If tables are available using units other than that given above, use factors below for conversion to ohm-inches.

ρ	ohm-cm	ohm-in	ohm-cir mil/ft
1 ohm-cm =	1.000	0.3937	6.015×10^{6}
1 ohm-in =	2.540	1.000	1.528×10^{7}
1 ohm-cir mil/ft =	1.662×10^{-7}	6.545×10^{-8}	1.000

Conversion Factors for Electrical Resistivity

(52)	ρ_S (hot)	**RESISTIVITY OF STATOR WINDING** - Hot at X_s $^{\circ}$C in micro ohm-inches

$$\rho_{S(hot)} = (\rho_S)\left[\frac{(X_s\,^{\circ}C) + 234.5}{254.5}\right] = (51)\left[\frac{(50) + 234.5}{254.5}\right]$$

(53)	R_{SPH} (cold)	STATOR RESISTANCE/PHASE - Cold @ 20°C in ohms

$$R_{SPH(cold)} = \frac{(\rho_S)(n_s)(Q)(\ell_t)}{(m)(a_c)(C)^2} \times 10^{-6} = \frac{(51)(30)(23)(49)}{(5)(46)(32)^2} \times 10^{-6}$$

(54)	R_{SPH} (hot)	STATOR RESISTANCE/PHASE - Calculated @ X°C in ohms

$$R_{SPH(hot)} = \frac{(\rho_S\ hot)(n_s)(Q)(\ell_t)}{(m)(a_c)(C)^2} \times 10^{-6}\ \frac{(52)(30)(23)(49)}{(5)(46)(32)^2} \times 10^{-}$$

(55)	EF (top)	**EDDY FACTOR TOP** - The eddy factor of the top coil. Calculate this value at the expected operating temperature of the machine. For round wire $EF_{top} = 1$

$$EF_{top} = 1 + \left\{ .584 + \left[\frac{(N_{st})^2 - 1}{16} \right] \left[\frac{(h'_{st})(\ell)}{(h_{st})(\ell_t)} \right]^2 \right\} 3.35 \times 10^{-3} \left[\frac{(h_{st})(n_s)(f)(a_c)}{(b_s)(\rho_{S\,hot})} \right]^2$$

$$= 1 + \left\{ .584 + \left[\frac{(34)^2 - 1}{16} \right] \left[\frac{(38)(13)}{(37)(49)} \right]^2 \right\} 3.35 \times 10^{-3} \left[\frac{(37)(30)(5a)(46)}{(22)(52)} \right]^2$$

(56) EF (bot) EDDY FACTOR BOTTOM - The eddy factor of the bottom coil at the expected operating temperature of the machine. For round wire $EF_{(bot)} = 1$

$$EF_{(bot)} = (EF_{(top)}) - 1.677 \left[\frac{(h_{st})(n_s)(f)(a_c)}{(b_s)(\rho_{S\,hot})} \right]^2 \times 10^{-3}$$

$$= (55) - 1.677 \left[\frac{(37)(30)(5a)(46)}{(22)(52)} \right] 10^{-3}$$

(57) b_{tm} STATOR TOOTH WIDTH 1/2 way down tooth in inches - For slots type (a), (b), (d) and (e), item (21).

$$b_{tm} = \frac{\pi \left[(d) + (h_s) \right]}{(Q)} - (h_s) = \frac{\pi \left[(11) + (22) \right]}{(23)} - (22)$$

For slot type (c), item (21).

$$b_{tm} = \frac{\pi\left[(d) + 2(h_s)\right]}{(Q)} - (b_3) = \frac{\pi\left[(11) + 2(22)\right]}{(23)} - (22)$$

(57a) $b_{t1/3}$ STATOR TOOTH WIDTH 1/3 distance up from narrowest section

For slots type (a), (b) and (e)

$$b_{t\ 1/3} = (\tau_{s\ 1/3}) - (b_s) = (27) - (22)$$

For slot type (c)

$$b_{t\ 1/3} = b_{tm} = (57)$$

For slot type (d)

$$b_{t\ 1/3} = (\tau_{1/3}) - \frac{2\sqrt{2}}{3}(b_s) = (27) - .94(22)$$

(58) b_t TOOTH WIDTH AT STATOR I.D. in inches -

For partially closed slot

$$b_t = \frac{\pi(d)}{(Q)} - (b_0) = \frac{\pi(11)}{(23)} - (22)$$

For open slot

$$b_t = \frac{\pi(d)}{(Q)} - (b_s) = \frac{\pi(11)}{(23)} - (22)$$

(59) g_{min} MINIMUM AIR GAP in inches - For concentric pole face

$g_{min} = g_{max}$. For non concentric pole face

g_{min} = gap at the center of the pole.

(59g) g_{max} MAXIMUM AIR GAP in inches

(60) C_X **REACTANCE FACTOR** - Used in calculating conductor permeance and is dependent on the pitch and distribution factor. This factor can be obtained from Curve F-5 with an assumed K_d of .955 or calculated as shown

$$C_X = \frac{(K_X)}{(K_p)^2\,(K_d)^2} = \frac{(61)}{(44)^2\,(43)^2}$$

(61) K_X Factor to account for difference in phase current in coil sides in same slot.

For 60° phase belt winding, ie when (42a) = 60

$$K_X = 1/4\left[\frac{3(y)}{(m)(q)} + 1\right] \text{ where } 2/3 \leqq (y)/(m)(q) \leqq 1.0$$

$$K_X = 1/4\left[\frac{3(31)}{(5)(25)} + 1\right] \text{ where } 2/3 \leqq (31a) \leqq 1.0$$

or

$$K_X = 1/4\left[\frac{6(y)}{(m)(q)} - 1\right] \text{ where } 1/2 \leqq (31a) \leqq 2/3$$

$$K_X = 1/4\left[\frac{6(31)}{(5)(25)} - 1\right] \text{ where } 1/2 \leqq (31a) \leqq 2/3$$

For 120° phase belt winding, ie when (42a) = 120

$$K_X = .75 \text{ when } 2/3 \leqq (y)/(m)(q)$$

$$K_X = .75 \text{ when } 2/3 \leqq (31a)$$

or

$$K_X = .05\left[\frac{24(y)}{(m)(q)} - 1\right] \text{ where } 1/2 \leqq \frac{(y)}{(m)(q)} \leqq 2/3$$

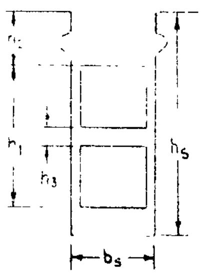
$$K_X = .05\left[\frac{24(31)}{(3)(25)} - 1\right] \text{ where } 1/2 \leqq (31a) \leqq 2/3$$

(62)	λ_i

CONDUCTOR PERMEANCE - The specific permeance for the portion of the stator current that is embedded in the iron. This permeance depends upon the configuration of the slot. (flux lines per ampere turn, per inch of stator stack).

(a) Open Slots

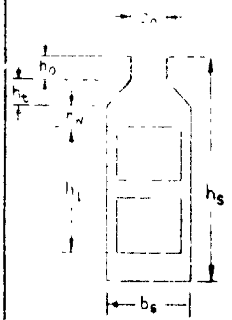
(a) For open slots



$$\lambda_i = (C_X)\frac{20}{(m)(q)}\left[\frac{(h_2)}{(b_s)}+\frac{(h_1)}{3(b_s)}+\frac{(b_t)^2}{16(\tau_s)(g)}+\frac{.35(b_t)}{(\tau_s)}\right]$$

$$\lambda_i = (60)\frac{20}{(5)(25)}\left[\frac{(22)}{(22)}+\frac{(22)}{3(22)}+\frac{(58)^2}{16(26)(59)}+\frac{.35(58)}{(26)}\right]$$

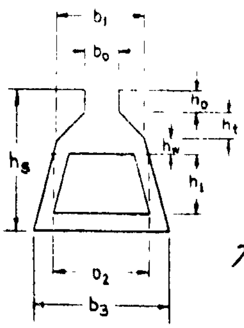
(b) Constant Slot Width **(b) For partially closed slots with constant slot width**



$$\lambda_i = (C_X)\frac{20}{(m)(q)}\left[\frac{(h_o)}{(b_o)}+\frac{2(h_t)}{(b_o)+(b_s)}+\frac{(h_w)}{(b_s)}+\frac{(h_1)}{3(b_s)}+\frac{(b_t)^2}{16(\tau_s)(g)}+\frac{.35(b_t)}{(\tau_s)}\right]$$

$$\lambda_i = (60)\frac{20}{(5)(25)}\left[\frac{(22)}{(22)}+\frac{2(22)}{(22)+(22)}+\frac{(22)}{(22)}+\frac{(22)}{3(22)}+\frac{(58)^2}{16(26)(59)}+\frac{.35(58)}{(26)}\right]$$

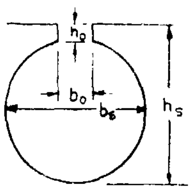
(c) Constant Tooth Width **(c) For partially closed slots (tapered sides)**



$$\lambda_i = (C_X)\frac{20}{(m)(q)}\left[\frac{(h_o)}{(b_o)}+\frac{2(h_t)}{(b_o)+(b_1)}+\frac{2(h_w)}{(b_1)+(b_2)}+\frac{(h_1)}{3(b_2)}+\frac{(b_t)^2}{16(\tau_s)(g)}+\frac{.35(b_t)}{(\tau_s)}\right]$$

$$\lambda_i = (60)\frac{20}{(5)(25)}\left[\frac{(22)}{(22)}+\frac{2(22)}{(22)+(22)}+\frac{2(22)}{(22)+(22)}+\frac{(22)}{3(22)}+\frac{(58)^2}{16(26)(59)}+\frac{.35(58)}{(26)}\right]$$

(d) Round Slots



(d) For round slots

$$\lambda_i = (C_X)\,\frac{20}{(m)(q)}\left[.62 + \frac{(h_o)}{(b_o)}\right]$$

$$\lambda_i = (60)\,\frac{20}{(5)(25)}\left[.62 + \frac{(22)}{(22)}\right]$$

(e) For open slots with a winding of one conductor per slot

$$\lambda_i = (C_X)\,\frac{20}{(m)(q)}\left[\frac{(h_2)}{(b_s)} + \frac{(h_1)}{3(b_s)} + .6 + \frac{(g)}{2(\tau_s)} + \frac{(\tau_s)}{4(g)}\right]$$

$$\lambda_i = (60)\,\frac{20}{(5)(25)}\left[\frac{(22)}{(22)} + \frac{(22)}{3(22)} + .6 + \frac{(59)}{2(26)} + \frac{(26)}{4(59)}\right]$$

(63) K_E **LEAKAGE REACTIVE FACTOR** for end turn

$$K_E = \frac{\text{Calculated value } (L_E)}{\text{Value } (L_E) \text{ from Curve F-1}} \quad \text{(For machines where (11)} > 8\text{")}$$

where L_E = (48) and abscisa of Graph 1 = $(\gamma)(\tau_s)$ = (31)(26)

$$K_E = \sqrt{\frac{\text{Calculated value of } (L_E)}{\text{Value } (L_E) \text{ from Curve F-1}}} \quad \text{(For machines where (11)} < 8\text{")}$$

(64) λ_E **END WINDING PERMEANCE** - The specific permeance for the end extension portion of the stator winding*

$$\lambda_E = \frac{6.28(K_E)}{(\ell)(K_d)^2}\left[\frac{\phi_E\, L_E}{2n}\right] = \frac{6.28(63)}{(13)(43)^2}\left[\frac{Q_E\, L_E}{2n}\right]$$

The term $\left[\frac{\phi_E\, L_E}{2n}\right]$ is obtained from Curve F-1

The symbols used in this (term) do not apply to those of this design manual. Reference information for the symbol origin is included on Curve F-1.

* See (62) for units

(65)	--	**WEIGHT OF COPPER** - The weight of stator copper in lbs. #'s copper = $.321(n_s)(Q)(a_c)(\ell_t) = .321(30)(23)(46)(49)$ NOTE: This answer is given in lbs. based on the density of copper. If any other material is used, the answer on output sheet can be converted by the designer by multiplying by the ratio of densities.
(66)	--	**WEIGHT OF STATOR IRON** - in lbs. #'s iron = $.283\left\{(b_{tm})(Q)(\ell_s)(h_s) + \pi\left[(D) - (h_c)\right](h_c)(\ell_s)\right\}$ $.283\left\{(57)(23)(17)(22) + \pi\left[(12) - (24)\right](24)(17)\right\}$
(67)	K_s	**CARTER COEFFICIENT** $K_s = \dfrac{(\tau_s)\left[5(g) + (b_s)\right]}{(\tau_s)\left[5(g) + (b_s)\right] - (b_s)^2}$ (For open slots) $K_s = \dfrac{(26)\left[5(59) + (22)\right]}{(26)\left[5(59) + (22)\right] - (22)^2}$ $K_s = \dfrac{\tau_s\left[4.44(g) + .75(b_o)\right]}{\tau_s\left[4.44(g) + .75(b_o)\right] - (b_o)^2}$ (For partially closed slots) $K_s = \dfrac{(26)\left[4.44(59) + .75(22)\right]}{(26)\left[4.44(59) + .75(22)\right] - (22)^2}$

(68) A_g **AIR GAP AREA** - The area of the gap surface at the stator bore

Gap Area = $\pi(d)(\ell) = \pi(11)(13)$ (in square inches)

(69) g_e **EFFECTIVE AIR GAP** (in square inches)

$$g_e = (K_s)(g) = (67)(59)$$

(70) λ_a **AIR GAP PERMEANCE** - The specific permeance of the air gap (See (62) for units.)

$$\lambda_a = \frac{6.38(d)}{(P)(g_e)} = \frac{6.38(11)}{(6)(69)}$$

(71) C_1 **THE RATIO OF MAXIMUM FUNDAMENTAL** of the field form to the actual maximum of the field form - This term can be an input or output. For C_1 to be output insert 0. on input sheet and the computer program will calculate it. For C_1 to be input, determine C_1 as follows:

For pole heads with only one radius, C_1 is obtained from curve F-4. The abscisa is "pole embrace" (α) = (77). The graphical flux plotting method of determining C_1 is explained in the section titled "Derivations" in the Appendix

(72) C_W **WINDING CONSTANT** - The ratio of the RMS line voltage for a full pitched winding to that which would be induced in all the phase conductors in series if the density were uniform and equal to the maximum value. This value

can be an input or output. To have the program calculate C_W, insert 0. on input sheet. For C_W to be an input, calculate as follows:

$$C_W = \frac{(E)(C_1)(K_d)}{\sqrt{2}\,(E_{PH})(m)} = \frac{(3)(71)(43)}{\sqrt{2}\,(4)(5)}$$

Assuming $K_d = .955$, then $C_W = .225\ C_1$ for three phase delta machines and $C_W = .390\ C_1$ for three phase star machines.

(73) C_P POLE CONSTANT - The ratio of the average to the maximum value of the field form. This ratio can be an input or output. To have the program calculate C_P, insert 0. on input sheet. For C_P to be an input, determine as follows:

For pole heads with more than one radius C_P is calculated from the same field form that was used to determine C_1, and this method is described in the section titled "Derivations" in the Appendix

For pole heads with only one radius, C_P is obtained from curve F-4. Note the correction factor at the top of the curve.

(74) C_M DEMAGNETIZING FACTOR - direct axis - This factor can be an input or output. For C_M to be an output, insert 0. on input sheet. For C_M to be an input, determine as follows:

$$C_M = \frac{(\alpha)\pi + \sin[(\alpha)\pi]}{4\sin[(\alpha)\ \pi/2]} = \frac{(77)\pi + \sin[(77)\pi]}{4\sin[(77)\ \pi/2]}$$

C_M can also be obtained from curve F-9

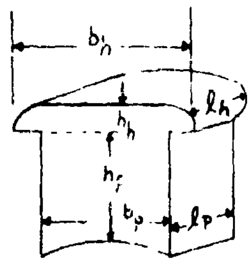
(75) | C_q | **CROSS MAGNETIZING FACTOR** - quadrature axis - This factor can be an input or output. For C_q to be an output, insert 0. on input sheet. For C_q to be an input, determine as follows:

$$C_q = \frac{1/2\cos[(\alpha)\ \pi/2] + (\alpha)\pi - \sin[(\alpha)\pi]}{4\sin[(\alpha)\ \pi/2]} = \frac{1/2\cos[(77)\ \pi/2] + (77)\pi - \sin[(77)\pi]}{4\sin[(77)\ \pi/2]}$$

valid for concentric poles

C_q can also be obtained from curve F-9

(76) | -- | **POLE DIMENSIONS LOCATIONS**



Where:

b_h = width of pole head
b_p = width of pole body
h_h = height of pole head at center
h_f = height of pole body
ℓ_p = length of pole body
ℓ_h = length of pole head

all dimensions in inches

(77) | α | **POLE EMBRACE**

$$\alpha = \frac{b_h}{\tau_p} = \frac{(76)}{(41)}$$

(79)	a_p	**POLE AREA** - The effective cross sectional area of the pole. $$a_p = (b_p)(\ell_p)(K_i) = (76)(76)(16) \quad \text{(square inches)}$$
(80b)	$\lambda_{s\ell}$	**POLE SIDE LEAKAGE PERMEANCE** - See (62) for units $$\lambda_{s\ell} = \left\{ \frac{(h_f)}{\pi/(P)\left[(d_r) - 2(h_h) - .5(h_f)\right] - (b_p)} \right\}$$ $$= \left\{ \frac{(76)}{\pi/(6)\left[(11a) - 2(76) - .5(76)\right] - (76)} \right\}$$
(81b)	$\lambda_{t\ell}$	**POLE TIP LEAKAGE PERMEANCE** - See (62) for units $$\lambda_{t\ell} = \left\{ \frac{2\left[(h_h) + (g) - (\tau_p)/18\right]}{(\tau_p) - (b_h)} \right\}$$ $$= \left\{ \frac{2\left[(76) + (59) - (41)/18\right]}{(41) - (76)} \right\}$$
(82b)	$\lambda_{e\ell}$	**POLE END LEAKAGE PERMEANCE** - See (62) for units $$\lambda_{e\ell} = \left\{ \frac{2\left[(\ell_h) - (\ell)\right] + (h_f) + .25(b_p)}{(\ell)} \right\}$$ $$= \left\{ \frac{2\left[(76) - (13)\right] + (76) + .25(76)}{(13)} \right\}$$
(87)	--	**NO LOAD SATURATION CALCULATIONS** - The equations, items (88) to (127) are used to calculate points for the no-load saturation curve. Insert 1. on input sheet for "No Load Sat." The computer will cal-

culate the no load saturation points at 80, 90, 100, 110, 120, 130, 140, 150 and 160% of rated volts. If the complete saturation data is not necessary, insert 0. on input sheet and the computer will calculate only the 100% volt data.

(88) ϕ_T TOTAL FLUX IN KILO LINES

$$\phi_T = \frac{6(E)10^6}{(C_W)(n_e)(RPM)} = \frac{6(3)10^6}{(72)(45)(7)}$$

(91) B_t TOOTH DENSITY in Kilo Lines/in^2 - The flux density in the stator tooth at 1/3 of the distance from the minimum section.

$$B_t = \frac{\phi_T}{(Q)(\ell_s)(b_{t\,1/3})} = \frac{(88)}{(23)(17)(57a)}$$

(92) ϕ_P FLUX PER POLE in Kilo Lines

$$\phi_P = \frac{(\phi_T)(C_P)}{(P)} = \frac{(88)(73)}{(6)}$$

(94) B_c CORE DENSITY in Kilo Lines/in^2 - The flux density in the stator core

$$B_c = \frac{(\phi_P)}{2(h_c)(\ell_s)} = \frac{(92)}{2(24)(17)}$$

(95) B_g GAP DENSITY in Kilo Lines/in^2 - The maximum flux density in the air gap

$$B_g = \frac{(\phi_T)}{\pi(d)(\ell)} = \frac{(88)}{\pi(11)(13)}$$

(96)	F_g	**AIR GAP AMPERE TURNS** - The field ampere turns per pole required to force flux across the air gap when operating at no load with rated voltage. $$F_g = \frac{(B_g)(g_e) \times 10^3}{3.19} = \frac{(95)(69) \times 10^3}{3.19}$$
(97)	F_T	**STATOR TOOTH AMPERE TURNS** $$F_T = h_s \left[\text{NI/in at density } B_t \right]$$ $$= (22) \left[\begin{array}{l} \text{Look-up on stator magnetization curve given in} \\ \text{(18) @ density (91)} \end{array} \right]$$
(98)	F_c	**STATOR CORE AMPERE TURNS** $$F_c = \left[\frac{\pi \left[(D) - (h_c) \right]}{4(P)} \right] \left[\text{NI/in @ density of} \left(B_c \right) \right]$$ $$= \left[\frac{\pi \left[(12) - (24) \right]}{4(6)} \right] \left[\begin{array}{l} \text{Look-up on stator magnetization curve} \\ \text{given in (18) @ density (94)} \end{array} \right]$$
(98a)	F_s	**STATOR AMPERE TURNS**, total $$F_s = (F_T) + (F_c) = (97) + (98)$$
(100a)	ϕ_ℓ	**LEAKAGE FLUX** - at no load $$\phi_\ell = .00638 \left[(\lambda_{s\ell}) + (\lambda_{e\ell}) + (\lambda_{t\ell}) \right] \left[(F_g) + (F_S) \right] (\ell_P)$$ $$= .00638 \left[(80b) + (82b) + (81b) \right] \left[(96) + (98a) \right] (76)$$

(102a) ϕ_{PT} **TOTAL FLUX PER POLE - at no load**

$$\phi_{PT} = \phi_P + \phi_\ell = (92) + (100a)$$

(103a) B_P **POLE DENSITY** - The flux density at the base of the pole. Note that no provision is made in this manual for calculating the density in the spider section. It is, therefore, important to remember not to restrict the flux area through this section.

$$B_P = \frac{(\phi_{PT})}{(a_P)} = \frac{(102a)}{(79)}$$

(104a) F_P **POLE AMPERE TURNS** - at no load. The ampere turns per pole required to force the flux through the pole and spider at no load rated voltage. In general the spider density is kept fairly low and its ampere turns can be neglected. The no load pole ampere turns per pole are calculated as the product of $\left[(h_f) + (h_h)\right]$ times the NI per inch at the density (B_P). Use magnetization curve submitted per item (18) for rotor.

$$F_P = \left[(h_f) + (h_h)\right]\left[\text{NI/in @ density } (B_P)\right]$$

$$= \left[(76) + (76)\right]\begin{bmatrix}\text{Look-up on rotor magnetization} \\ \text{curve given in (18) @ density(103a)}\end{bmatrix}$$

(127) F_{NL} **TOTAL AMPERE TURNS** - at no load. The total ampere turns per pole required to produce rated voltage at no load.

$$F_{NL} = \left[(F_g) + (F_S) + (F_P)\right] = \left[(96) + (98a) + (104a)\right]$$

(127a) I_{FNL} **FIELD CURRENT** - at no load

$$I_{FNL} = (F_{NL})/(N_P) = (127)/(146a)$$

(127b) E_F **FIELD VOLTS** - at no load. This calculation is made with cold field resistance at $20^{o}C$ for no load condition.

$$E_F = (I_{FNL})(R_{f\,cold}) = (127a)(154)$$

(127c) S_F **CURRENT DENSITY** - at no load. Amperes per square inch of field conductor.

$$S_F = (I_{FNL})/(a_{cf}) = (127a)(153)$$

(128) A **AMPERE CONDUCTORS** per inch - The effective ampere conductors per inch of stator periphery. This factor indicates the "specific loading" of the machine. Its value will increase with the rating and size of the machine and also will increase with the number of poles. It will decrease with increases in voltage or frequency. A is generally higher in single phase machines than in polyphase ones.

$$A = \frac{(I_{PH})(n_s)(K_P)}{(C)(\tau_s)} = \frac{(8)(30)(44)}{(32)(26)}$$

(129) X **REACTANCE FACTOR** - The reactance factor is the quantity by which the specific permeance must be multiplied to give percent reactance. Specific permeance is defined as the average flux per pole per inch of core length produced by unit ampere turns per pole.

$$X = \frac{100(A)(K_d)}{\sqrt{2}\,(C_1)(B_g) \times 10^3} = \frac{100\ (128)(43)}{\sqrt{2}\ (71)\ (95) \times 10^3}$$

(130) X_ℓ **LEAKAGE REACTANCE** - The leakage reactance of the stator for steady state conditions. When (5) = 3, calculate as follows:

$$X_\ell = X\left[(\lambda_i) + (\lambda_E)\right] = (129)\left[(62) + (64)\right] \text{ percent}$$

In the case of two phase machines a component due to belt leakage must be included in the stator leakage reactance. This component is due to the harmonics caused by the concentration of the MMF into a small number of phase belts per pole and is negligible for three phase machines. When (5) = 2, calculate as follows:

$$\lambda_B = \frac{0.1(d)}{(P)(g_e)}\left[\frac{\sin\left[\frac{3(y)}{(m)(q)}\right]90^0}{(K_p)}\right] = \frac{0.1(11)}{(6)(69)}\left[\frac{\sin\left[\frac{3(31)}{(5)(25)}\right]90^0}{(44)}\right]$$

$X_\ell = X\left[(\lambda_i) + (\lambda_E) + (\lambda_B)\right]$ where $\lambda_B = 0$ for 3 phase machines.

$$X_\ell = (79)\left[(62) + (64) + (130)\right] \text{ percent}$$

(131) X_{ad} **REACTANCE** - direct axis - This is the fictitious reactance due to armature reaction in the direct axis. (in percent)

$$X_{ad} = (X)(\lambda_a)(C_1)(C_M) = (129)(70c)(71)(74)$$

(132) X_{aq} **REACTANCE** - quadrature axis - This is the fictitious reactance due to armature reaction in the quad axis. (percent)

$$X_{aq} = (X)(C_q)(\lambda_a) = (129)(75)(70c)$$

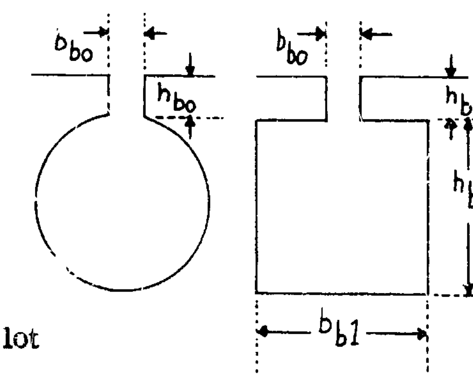
(133) X_d — SYNCHRONOUS REACTANCE - direct axis - The steady state short circuit reactance in the direct axis. (percent)

$$X_d = (X_\ell) + (X_{ad}) = (130) + (131)$$

(134) X_q — SYNCHRONOUS REACTANCE - quadrature axis - The steady state short circuit reactance in the quadrature axis.

$$X_q = (X_\ell) + (X_{aq}) = (130) + (132) \text{ (percent)}$$

(135) -- — DAMPER SLOT DIMENSIONS



b_{bo} - width of slot opening

h_{bo} - height of slot opening

h_b - diameter of round slot

h_{b1} - height of bar section of slot

b_{b1} - width of rectangular slot

All dimensions in inches

(136) -- — DAMPER BAR DIA OR WIDTH in inches

(137) h_{b1} — DAMPER BAR THICKNESS in inches - Damper bar thickness considered equal to damper bar slot height per item (135). Set this item = 0 for round bar.

(138) n_b — NUMBER OF DAMPER BARS PER POLE

(139) ℓ_b — DAMPER BAR LENGTH in inches

(140) τ_b — DAMPER BAR PITCH in inches

(141) ρ_D — RESISTIVITY of damper bar @ 20°C in micro ohm-inches - Refer to table given in item (51) for conversion factors.

(142)	$X_D\,^{o}C$	DAMPER BAR TEMP ^{o}C - Input temp at which damper losses are to be calculated.
(143)	ρ_D (hot)	RESISTIVITY of damper bar @ $X_D\,^{o}C$ $\rho_{D(hot)} = (\rho_D)\left[\frac{(X_D\,^{o}C) + 234.5}{254.5}\right] = (141)\left[\frac{(142) + 234.5}{254.5}\right]$

(144)	a_{cd}	CONDUCTOR AREA OF DAMPER BAR - Calculate same as stator conductor area
		 If (137) = 0
		 $a_{cd} = .25\pi$ (damper bar dia)^2 $= .25\pi(136)^2$
		 If (137) $\neq$ 0
		 $a_{cd} = (h_{b1})$ (damper bar width) = (137)(136)

(145)	V_r	PERIPHERAL SPEED - The velocity of the rotor surface in feet per minute $V_r = \frac{\pi(d_r)(RPM)}{12} = \frac{\pi(11a)(7)}{12}$
(146a)	N_P	NUMBER OF FIELD TURNS PER POLE
(147)	ℓ_{tr}	MEAN LENGTH OF FIELD TURN, inches
(148)	--	FIELD CONDUCTOR DIA OR WIDTH in inches
(149)	--	FIELD CONDUCTOR THICKNESS in inches - Set this item = 0. for round conductor

(150) $X_f\,^oC$ — FIELD TEMP IN ^oC - Input temp at which full load field loss is to be calculated.

(151) ρ_f — RESISTIVITY of rotor field conductor @ 20^oC in micro ohm-inches. Refer to table given in item (51) for conversion factors.

(152) ρ_f (hot) — RESISTIVITY of rotor field conductor at $X_f\,^oC$

$$\rho_{f\ (hot)} = \rho_f \left[\frac{(X_f\,^oC) + 234.5}{254.5} \right] = (151) \left[\frac{(150) + 234.5}{254.5} \right]$$

(153) a_{cf} — CONDUCTOR AREA OF ROTOR FIELD WDG - Calculate same as stator conductor area (46) except substitute

$$\begin{cases} (149) \text{ for } (39) \\ (148) \text{ for } (33) \end{cases}$$

(154) R_f (cold) — COLD FIELD RESISTANCE @ 20^oC

$$R_{f\ (cold)} = (\rho_f) \frac{(N_p)(P)(\ell_{tr}) \times 10^{-6}}{(a_{cf})} = (151) \frac{(146)(6)(147) \times 10^{-6}}{(153)}$$

(155) R_f (hot) — HOT FIELD RESISTANCE - Calculated at $X_f\,^oC$ (103)

$$R_{f\ (hot)} = (\rho_{f\ hot}) \frac{(N_p)(P)(\ell_{tr}) \times 10^{-6}}{(a_{cf})} = (152) \frac{(146a)(6)(147) \times 10^{-6}}{(153)}$$

(156) -- — WEIGHT OF ROTOR FIELD COPPER in lbs

The answer is given in lbs. based on the density of copper. If any other material is used, the answer on the output sheet can be converted by the designer by multiplying by the ratio of densities.

$$\#\text{'s of copper} = .321(N_p)(P)(\ell_{tr})(a_{cf})$$

$$= .321(146)(6)(147)(153)$$

(157) -- **WEIGHT OF ROTOR IRON** - Because of the large number of different pole shapes, one standard formula cannot be used for calculating rotor iron weight. Therefore the computer will not calculate rotor iron weight. The space is allowed on the input sheet for record purposes only. By inserting 0. in the space allowed for rotor iron weight, the computer will show "0." on the output sheet. If the rotor iron weight is available and inserted on input sheet, then the output sheet will show this same weight on the output sheet.

(158) λ_b **PERMEANCE OF DAMPER BAR** - The permeance of that portion of the damper bar that is embedded in pole iron. (See (62) for units)

For round slot

$$\lambda_b = 6.38\left[\frac{(h_{bo})}{(b_{bo})} + .62 + .5\right] = 6.38\left[\frac{(135)}{(135)} + .62 + .5\right]$$

For rectangular slot

$$\lambda_b = 6.38\left[\frac{(h_{bo})}{(b_{bo})} + \frac{(h_{b1})}{3(b_{b1})} + .5\right] = 6.38\left[\frac{(135)}{(135)} + \frac{(135)}{3(135)} + .5\right]$$

(159) λ_{pt} **PERMEANCE OF END PORTION OF DAMPER BARS**

$$\lambda_{pt} = 6.38\left\{\frac{(b_h) - (T_b)\left[(n_b) - 1\right]}{3(g_e)}\right\}$$

$$= 6.38\left\{\frac{(76) - (140)\left[(138) - 1\right]}{3(69)}\right\}$$

(160) X_F **FIELD LEAKAGE REACTANCE** in percent

$$X_F = (X_{ad}) \left[1 - \frac{\left[(C_1)/(C_m)\right]}{2(C_p) + \frac{4(\lambda_F)}{\pi(\lambda_a)}} \right]$$

$$= (131) \left[1 - \frac{\left[(71)/(74)\right]}{2(73) + \frac{4(161f)}{\pi(70c)}} \right]$$

(161) L_f **FIELD SELF INDUCTANCE**, henries

$$L_f = (N_P)^2(P)(\ell_P) \left[(C_P)(\lambda_a)\frac{\pi}{2} + (\lambda_f)\right] \times 10^{-8}$$

$$= (146a)^2(6)(76) \quad (73)(70c)\frac{}{2} - (161f) \quad \times 10^{-8}$$

(161f) λ_F **ROTOR LEAKAGE PERMEANCE** (See (62) for units)

$$\lambda_F = 4.25 \left[(\lambda_{s\ell}) + 1.5(\lambda_{t\ell})\right] + 6.38(\lambda_{e\ell})$$

$$= 4.25 \left[(80b) + 1.5(81b)\right] + 6.38\,(82b)$$

(162) λ_{Dd} **PERMEANCE OF DAMPER BAR** - in direct axis

$$\lambda_{Dd} = \left\{ \cos\left[\frac{\left\{(n_b) - 1\right\}(\tau_b)\pi}{2(\tau_P)} \right] \right\} \left\{ \frac{\left\{(\lambda_b) + (\lambda_{Pt})\right\}\ (\lambda_F)}{\lambda_b + \lambda_{Pt} + \lambda_F} \right\}$$

$$= \left\{ \cos\left[\frac{\left\{(138) - 1\right\}(140)}{2(41)} \right] \right\} \left\{ \frac{\left\{(158) + (159)\right\}(161f)}{(158) + (159) + (161f)} \right\}$$

(163)	X_{Dd}	DAMPER LEAKAGE REACTANCE - in direct axis (percent) $$X_{Dd} = X(\lambda_{Dd}) = (129)(162)$$
(164)	λ_{Dq}	PERMEANCE IN QUADRATURE AXIS See (62) for units For round slot $$\lambda_{D_q} = \frac{20(\tau_b)}{(\tau_p)}\left[\frac{(h_{bo})}{(b_{bo})} + .62 + .5 + \frac{(g)}{(\tau_b)}\right]$$ $$= \frac{20(140)}{(41)}\left[\frac{(135)}{(135)} + .62 + .5 + \frac{(59)}{(140)}\right]$$ For rectangular slot $$\lambda_{(Dq)} = \frac{20(\tau_b)}{(\tau_p)}\left[\frac{(h_{bo})}{(b_{bo})} + \frac{(h_{b1})}{3(b_{b1})} + .5 + \frac{(g)}{(\tau_b)}\right]$$ $$= \frac{20(140)}{(41)}\left[\frac{(135)}{(135)} + \frac{(135)}{3(135)} + .5 + \frac{(59)}{(140)}\right]$$
(165)	X_{Dq}	DAMPER LEAKAGE REACTANCE - in quadrature axis (percent) $$X_{Dq} = X(\lambda_{Dq}) = (129)(164)$$
(166)	X'_{du}	UNSATURATED TRANSIENT REACTANCE (percent) $$X'_{du} = (X_{\ell}) + (X_f) = (130) + (160)$$
(167)	X'_d	SATURATED TRANSIENT REACTANCE (percent) $$X'_d = .88(X'_{du}) = .88(166)$$

(168)	X_d''	SUBTRANSIENT REACTANCE in direct axis (percent) When damper bars exist, i.e. when(138) $\neq$ 0 $X_d'' = (X_\ell) + (X_{Dd}) = (130) + (163)$ When no damper bars exist, i.e. when(138) = 0 $X_d'' = (X_d') = (167)$
(169)	X_q''	SUBTRANSIENT REACTANCE in quadrature axis (percent) When damper bar exists, i.e. when(138) $\neq$ 0 $X_q'' = (X_\ell) + (X_{Dq}) = (130) + (165)$ When no damper bars exist, i.e. when(138) = 0 $X_q'' = X_q = (134)$
(170)	X_2	NEGATIVE SEQUENCE REACTANCE - The reactance due to the field which rotates at synchronous speed in a direction opposite to that of the rotor. (percent) $X_2 = .5\left[X_d'' + X_q''\right] = .5\left[(168) + (169)\right]$
(172)	X_0	ZERO SEQUENCE REACTANCE - The reactance drop across any one phase (star connected) for unit current in each of the phases. The machine must be star connected for otherwise no zero sequence current can flow and the term then has no significance. (in percent)

If (28) = 0 Then $X_o = 0$

If (28) $\neq$ 0 Then

$$X_o = X\left\{\frac{(K_{xo})}{(K_{x1})}\left[(\lambda_i) + (\lambda_{Bo})\right] + \frac{1.667\left[(h_1) + 2\,(h_s)\right]}{(m)(q)(K_p)^2(K_d)^2(b_s)} + .2(\lambda_E)\right\}$$

$$= (129)\left\{\frac{(173)}{(174)}\left[(62) + (175)\right] + \frac{1.667\left[(22) + 2\,(22)\right]}{(5)(25)(44)^2(43)^2(22)} + .2(64)\right\}$$

(173) K_{xo}

If (30) = 1 Then $K_{xo} = 1$

If (30) $\neq$ 1 Then $K_{xo} = \frac{3(Y)}{(m)(q)} - 2$

$$= \frac{3(31)}{(5)(25)} - 2$$

(174) K_{x1}

If (30) = 1 Then $K_{x1} = 1$

If (30) $\neq$ 1 Then:

$$K_{x1} = \left[\frac{3(Y)}{4(m)(q)} + \frac{1}{4}\right] = \left[\frac{3(31)}{4(5)(25)} + \frac{1}{4}\right] \quad \text{If } (31a) \geq .667$$

$$K_{x1} = \left[\frac{3(Y)}{4(m)(q)} - \frac{1}{4}\right] = \left[\frac{3(31)}{4(5)(25)} - \frac{1}{4}\right] \quad \text{If } (31a) < .667$$

(175) λ_{Bo}

If (92) = 0 Then:

$$\lambda_{Bo} = \frac{(K_{xo})}{(K_p)^2}\left[.07(\lambda_a)\right] = \frac{(173)}{(44)^2}\left[.07(70c)\right]$$

If (138) $\neq$ 0 Then
$$\lambda_{Bo} = \frac{\frac{(K_{xo})}{(K_{x1})}(\lambda_{Dq}) + \frac{(K_{xo})}{(K_p)^2}\left[.07(\lambda_a)\right]}{\left\{\frac{(K_{xo})}{(K_{x1})}(\lambda_{Dq})\right\}\left\{\frac{(K_{xo})}{(K_p)^2}\left[.07(\lambda_a)\right]\right\}}$$

$$= \frac{\frac{(173)}{(174)}(164) + \frac{(173)}{(44)^2}\left[.07(70c)\right]}{\left\{\frac{(173)}{(174)}(164)\right\}\left\{\frac{(173)}{(44)^2}\left[.07(70c)\right]\right\}}$$

If $(K_{XO}) = 0, (\lambda_{bo}) = 0$

$(173) = 0, \quad (175) = 0$

(176) T'_{do} **OPEN CIRCUIT TIME CONSTANT** - The time constant of the field winding with the stator open circuited and with negligible external resistance and inductance in the field circuit. Field resistance at room temperature ($20^{\circ}C$) is used in this calculation. (seconds)

$$T'_{do} = \frac{L_F}{R_F} = \frac{(161)}{(154)}$$

See appendix for explanation of time constants

(177) T_a **ARMATURE TIME CONSTANT** - Time constant of th D.C. component. In this calculation stator resistance at room temperature ($20^{\circ}C$) is used. (seconds)

$$T_a = \frac{X_2}{200\pi(f)(r_a)} = \frac{(170)}{200\pi(5a)(177)}$$

$$\text{where } r_a = \frac{(m)(I_{PH})^2(R_{SPH\ cold})}{(\text{Rated KVA}) \times 10^3} = \frac{(5)(8)^2(53)}{(2) \times 10^3}$$

(178) T'_d **TRANSIENT TIME CONSTANT** - The time constant of the transient reactance component of the alternating wave. (seconds)

$$T'_d = \frac{(X'_d)}{(X_d)}(T'_{do}) = \frac{(167)}{(133)}(176)$$

(179) T''_d — <u>SUBTRANSIENT TIME CONSTANT</u> - The time constant of the subtransient component of the alternating wave. This value has been determined empirically from tests on large machines. Use following values.

$$T''_d = .035 \text{ second at 60 cycle}$$

$$T''_d = .005 \text{ second at 400 cycle}$$

(180) F_{SC} — <u>SHORT CIRCUIT AMPERE TURNS</u> - The field ampere turns required to circulate rated stator current when the stator is short circuited.

$$F_{SC} = (X_d)(F_g) = (133)(36)$$

(181) SCR — <u>SHORT CIRCUIT RATIO</u> - The ratio of the field current to produce rated voltage on open circuit to the field current required to produce rated current on short circuit.

Since the voltage regulation depends on the leakage reactance and the armature reaction, it is closely related to the current which the machine produces under short circuit conditions, and therefore is directly related to the SCR.

$$SCR = \frac{F_{NL}}{F_{SC}} = \frac{(127)}{(180)}$$

(182)	I^2R_R	ROTOR I^2R - at no load. The copper loss in the field winding is calculated with cold field resistance at 20^oC for no load condition. (watts) $$\text{Rotor } I^2R = (I_{FNL})^2 (R_{f\,cold}) = (127a)^2 (154)$$
(183)	F & W	FRICTION & WINDAGE LOSS (Watts) - Note: Write 0 on input sheet when computer is to calculate F & W. Insert actual value when known. To ratio from test data, assume that F & W loss varies as the 5/2 power of the rotor diameter and as the 3/2 power of the RPM. The formula below gives an approximate answer when test data is not available. For a more rigorous treatment use the information given in the rotor friction analysis appended to the thermal analysis section (Section C, Vol. 1). $$F \,\&\, W = 2.52 \times 10^{-6} (d_r)^{2.5} (\ell_h) (RPM)^{1.5}$$ $$= 2.52 \times 10^{-6} (11a)^{2.5} (76) (7)^{1.5}$$ For gases or fluids other than standard air, the fluid density and viscosity must be considered. The formula given in the manual can be modified by the factors $$\left(\frac{\rho}{.0765}\right)^{.8} \left(\frac{u}{.0435}\right)^{.2}$$

where

ρ - density - Lbs FT^{-3}

μ - viscosity LBS FT^{-1} HR^{-1}

.0765 - density std. air

.0435 - viscosity std. air

(184) W_{TNL} STATOR TEETH LOSS - at no load. The no load loss (W_{TNL}) consists of eddy current and hysteresis losses in the iron. For a given frequency the no load tooth loss will vary as the square of the flux density. (watts)

$$W_{TNL} = .453(b_{t\,1/3})(Q)(\ell_s)(h_s)(K_Q)$$

$$= .453(57a)(23)(17)(22)(184)$$

$$\text{Where } K_Q = (k)\left[\frac{(B_t)}{(B)}\right]^2 = (19)\left[\frac{(91)}{(20)}\right]^2$$

(185) W_c STATOR CORE LOSS - The stator core losses are due to eddy currents and hysteresis and do not change under load conditions. For a given frequency the core loss will vary as the square of the flux density (B_c). (watts)

$$W_c = 1.42\left[(D) - (h_c)\right](h_c)(\ell_s)(K_Q)$$

$$= 1.42\left[(12) - (24)\right](24)(17)(185)$$

$$\text{Where } K_Q = (k)\left[\frac{(B_c)}{(B)}\right]^2 = (19)\left[\frac{(94)}{(20)}\right]^2$$

(186)	W_{NPL}	POLE FACE LOSS - at no load. The pole surface losses are due to slot ripple caused by the stator slots. They depend upon the width of the stator slot opening, the air gap, and the stator slot ripple frequency. The no load pole face loss (W_{PNL}) can be obtained from Curve F-2. Curve F-2 is plotted on the bases of open slots. In order to apply this curve to partially open slots, substitute b_o for b_s. For a better understanding of Curve F-2, use the following sample.

K_1 as given on Curve F-2 is derived empirically and depends on lamination material and thickness. Those values given on Curve F-2 have been used with success. K_1 is an input and must be specified. See item (187) for values of K_1.

K_2 is shown as being plotted as a function of $(B_G)^{2.5}$. Also note that upper scale is to be used. Another note in the lower right hand corner of graph indicates that for a solid line (——), the factor is read from the left scale, and for a broken or dashed line (— - — -), the right scale should be read. For example, find K_2 when B_g = 30 kilo lines. First locate 30 on upper scale. Read down to the intersection of solid line plot of $K_2 = fn(B_G)^{2.5}$. At this intersection read the left scale for K . K_2 = .28. Also refer to item (188) for K_2 calculations.

K_3 is shown as a solid line plot as a function of $(F_{SLT})^{1.65}$. The note on this plot indicates that the upper scale X 10 should be used. Note F_{SLT} = slot frequency. For an example, find K_3 when F_{SLT} = 1000. Use upper scale X 10 to locate 1000. Read down to intersection of solid line plot of $K_3 = f(F_{SLT})^{1.65}$. At this intersection read the left scale for K_3. $K_3 = 1.35$. Also refer to item (189) for K_3 calculations.

For K_4 use same procedure as outlined above except use lower scale. Do not confuse the dashed line in this plot with the note to use the right scale. The note does not apply in this case. Read left scale. Also refer to item (190) for K_4 calculations.

For K_5 use bottom scale and substitute b_o for b_s when using partially closed slot. Read left scale when using solid plot. Use right scale when using dashed plot. Also refer to item (191) for K_5 calculations.

For K_6 use the scale attached for C_1 and read K_6 from left scale. Also refer to item (192) for K_6 calculations.

The above factors (K_2), (K_3), (K_4), (K_5), (K_6) can also be calculated as shown in (188), (189), (190), (191), (192), respectively.

$$W_{PNL} = \pi(d)(\ell)(K_1)(K_2)(K_3)(K_4)(K_5)(K_6)$$

$$= \pi(11)(13)(187)(188)(189)(190)(191)(192)$$

(187) K_1 — K_1 is derived empirically and depends on lamination material and thickness. The values used successfully for K_1 are shown on Curve F-2. They are:

K_1 = 1.17 for .028 lam thickness, low carbon steel
= 1.75 for .063 lam thickness, low carbon steel
= 3.5 for .125 lam thickness, low carbon steel
= 7.0 for solid core

K_1 is an input and must be specified on input sheet.

(188) K_2 — K_2 can be obtained from Curve F-2 (see item (186) for explanation) or it can be calculated as follows:

$$K_2 = fn(B_G) = 6.1 \times 10^{-5} (B_G)^{2.5}$$

$$= 6.1 \times 10^{-5} (95)^{2.5}$$

(189) K_3 — K_3 can be obtained from Curve F-2 (see item (186) for explanation) or it can be calculated as follows:

$$K_3 = fn(F_{SLT}) = 1.5147 \times 10^{-5} (F_{SLT})^{1.65}$$

$$= 1.5147 \times 10^{-5} (189)^{1.65}$$

$$\text{Where } F_{SLT} = \frac{(RPM)}{60} (Q)$$

$$= \frac{(7)}{60} (23)$$

(190) K_4 — K_4 can be obtained from Curve F-2 (see item (186) for explanation) or it can be calculated as follows:

For $\gamma_s \leqq .9$

$$K_4 = fn(\gamma_s) = .81(\gamma_s)^{1.285}$$

$$= .81(26)^{1.285}$$

For $.9 \leqq \tau_s \leqq 2.0$

$$K_4 = fn(\ _s) = .79(\tau_s)^{1.145}$$

$$= .79(26)^{1.145}$$

For $\tau_s > 2.0$

$$K_4 - fn(\ _s) = .92(\tau_s)^{.79}$$

$$= .92(26)^{.79}$$

(191) | K_5 | K_5 can be obtained from Curve F-2 (see item (186 for explanation) or it can be calculated as follows:

For $(b_s)/(g) \leqq 1.7$

$$K_5 = fn(b_s/g) = .3\left[(b_s)/(g)\right]^{2.31}$$

$$= .3\left[(22)/(59)\right]^{2.31}$$

NOTE: For partially open slots substitute b_o for b_s in equations shown.

For $1.7 < (b_s)/(g) \leqq 3$

$$K_5 = fn(b_s)/(g) = .35\left[(b_s)/(g)\right]^2$$

$$= .35\left[(22)/(59)\right]^2$$

For $3 < (b_s)/(g) \leqq 5$

$$K_5 = fn(b_s)/(g) \quad .625\left[(b_s)/(g)\right]^{1.4}$$

$$= .625\left[(22)/(59)\right]^{1.4}$$

For $(b_s)/(g) > 5$

$$K_5 = \cancel{fn}\left[(b_s)\right]/(g) = 1.38\left[(b_s)/(g)\right]^{.965}$$

$$= 1.38\left[(22)/(59)\right]^{.965}$$

(192) | K_6 | K_6 can be obtained from Curve F-2 (see item (186) for explanation) or it can be calculated as follows:

$$K_6 = \cancel{fn}(C_1) = 10\left[.9323(C_1) - 1.60596\right]$$

$$= 10\left[.9323(71) - 1.60596\right]$$

(193) | W_{DNL} | DAMPER LOSS - at no load at 20^oC. This loss is produced by slot ripple in the damper winding. At no load this loss is calculated from curves F-7 and F-8.

$$W_{DNL} = \frac{1.246(P)(n_b)(\ell_b)(\rho_D)}{(a_{cd}) \times 10^3}\left[(\tau_s)(B_g)(K_{P1})(K_g)\right]^2$$

$$\left\{(K_{f1})\left[\frac{K_{W1}}{2(\lambda_s) + \left[(\lambda_g)/(K_{\phi i})\right]}\right]^2 + (K_{f2})\left[\frac{(K_{W2})}{2(\lambda_s) + \left[(\lambda_g)/(K_{\phi 2})\right]}\right]\right\}$$

$$W_{DNL} = \frac{1.246(6)(138)(139)(141)}{(144) \times 10^3}\left[(26)(95)(193)(193)\right]^2$$

$$\left\{(193)\left[\frac{(193)}{2(193)+\left[(193)/(193)\right]}\right]^2 + (193)\left[\frac{(193)}{2(193)+\left[(193)/(193)\right]}\right]^2\right\}$$

(193)	(Cont.)	Where $K_{p1} = 1 - \dfrac{1}{\sqrt{1 + \left[(b_s)/2(g)\right]^2}}$ $= 1 - \dfrac{1}{\sqrt{1 + \left[(22)/2(59)\right]^2}}$ NOTE: Substitute b_o for b_s when partially opened stator slot is used. K_{p1} can also be obtained from curve F-7 where abscissa is $(b_s)/(g)$ or $(b_o)/(g) = (22)/(59)$ Where $K_g = (K_s) = (67)$ Where $g' = (K_g)(g) = (193)(59)$ Where K_{f1} & K_{f2} are obtained from curve F-7 Where the abscissa is S_1 or S_2 $S_1 = .32 \sqrt{\dfrac{(f_{S1})}{(\rho_D)}}\,(h_b) = .32 \sqrt{\dfrac{(193)}{(141)}}\ (136)$ $S_2 = .32 \sqrt{\dfrac{(f_{S2})}{(\rho_D)}}\,(h_b) = .32 \sqrt{\dfrac{(193)}{(141)}}\ (136)$ Where $f_{S1} = 2qmf = 2(25)(5)(5a)$ $f_{S2} = 2(f_{S1})$ Where K_{W1} and K_{W2} are obtained from curve F-8 where the abscissa is $(b\ )/(\tau_s)$ for open slots or $(b_o)/(\tau_s)$ for semi-enclosed slots $(b_s)/(\tau_s) =$ (22) / (26)

(193)	(Cont.)	Where λ_t is obtained from curve F-7 Where the abscissa is $(b_{bo})/(g') = \frac{(135)}{(193)}$ When (91) = 0 or when (90) = (91) $\lambda_C = \frac{.75}{(K_{f1})} = \frac{.75}{(193)}$ For round or square slots When (137) $\neq$ 0 and when (136) $\neq$ (137) $\lambda_C = \frac{(h_{b1})}{3(b_{b1})(K_{f1})} = \frac{(137)}{3(135)(193)}$ Where $\lambda_S = \frac{(h_{bo})}{(b_{bo})} + (\lambda_t) + (\lambda_C)$ $= \frac{(135)}{(135)} + (193) + (193)$ Where $\lambda_g = \frac{(\tau b)}{(g')} = \frac{(140)}{(193)}$ Where $K_{\phi 1}$ and $K_{\phi 2}$ are obtained from curve F-8 Where the abscissa is $(\tau_b)/(\tau_s) = (140)/(26)$
(194)	I^2R	STATOR I^2R - at no load. This item = 0. Refer to item (245) for 100% load stator I^2R. (in watts)
(195)	--	EDDY LOSS - at no load. This item = 0. Refer to item (246) for 100% load eddy loss. (in watts)
(196)	--	TOTAL LOSSES - at no load. Sum of all losses. (in watts) **Total losses = (Rotor I^2R) + (F & W) + (Stator Teeth Loss) + (Stator Core Loss) + (Pole Face Loss) + (Damper Loss)** **= (182) + (183) + (184) + (185) + (186) + (193)**

NOTE: The output sheet shows the next items to be: (Rating), (Rating + Losses), (% Losses), (% ficiency). These items do not apply to the no load calculation since the rating is zero. Refer to items (248), (249) (177), (178) for these calculations under load.

Item (100) through (127c) have been calculated for 0% load or no load. They should all be repeated now for 100% load.

(197a) $\phi_{\ell\ell}$ <u>LEAKAGE FLUX PER POLE</u> at 100% load

$$\phi_{\ell\ell} = \phi_{\ell}\left\{\frac{(e_d)(F_g) + \left[1+\cos(\theta)\right](F_T) + (F_C)}{(F_g) + (F_T) + (F_C)}\right\}$$

$$= (100a)\ \frac{(198)\ (96) + \left[1+\cos(198a)\right]\ (97) + (98)}{(96) + (97) + (98)}$$

(198) e_d

$$\text{Where } e_d = \cos\epsilon + \frac{(X_d)}{100}\sin\psi$$

$$= \cos\,(198a) + \frac{(133)}{100}\sin\,(193a)$$

(198a) θ

$$\text{Where } \theta = \cos^{-1}\left[(\text{Power Factor})\right]$$

$$= \cos^{-1}\left[(9)\right]$$

$$\text{Where } \psi = \tan^{-1}\left[\frac{\sin(\theta) + (X_q)/(100)}{\cos(\theta)}\right]$$

$$= \tan^{-1}\left[\frac{\sin(160b) + (134)/(100)}{\cos(198a)}\right]$$

$$\text{Where } \epsilon = \psi - \theta = (198a) - (198a)$$

(213)	ϕ_{PL}	FLUX PER POLE at 100% load, Kilolines
		FOR P.F. 0 TO .95
		$\phi_{PL} = (\phi_P)\left[(e_d) - \frac{.93(X_{ad})}{100}\sin(\psi)\right]$
		$= (92)\left[(198) - \frac{.93(131)}{100}\sin(198a)\right]$
		FOR P.F. .95 TO 1.0 $\phi_{PL} = (\phi_P)(K_c) = (92)(9a)$
(213a)	ϕ_{PTL}	TOTAL FLUX PER POLE at 100% load, Kilolines
		$\phi_{PTL} = \phi_{PL} + \phi_{\ell\ell} = (213) + (197a)$
(213b)	B_{PL}	FLUX DENSITY AT BASE OF POLE at 100% load, Kl/in^2
		$B_{PL} = \frac{\phi_{PTL}}{a_P} = \frac{(213a)}{(79)}$
(213c)	F_{PL}	AMPERE TURNS PER POLE at 100% load
		$F_{PL} = \left[(h_f) + (h_h)\right]\left[NI/in @ density (B_{PL})\right]$
		$= \left[(76) + (76)\right]$ Look-up ampere turns/inch on rotor magnetization curve given in (18) at density (213b)
(236)	F_{FL}	TOTAL AMPERE TURNS PER POLE at 100% load - The total ampere turns per pole required to produce rated load.
		$F_{FL} = (e_d)(F_g) + \left[1 + \cos(\theta)\right](F_T) + (F_C) + (F_{PL})$
		$= (198)(96) + \left[1 + \cos(198a)\right](97) + (98) + (213c)$
(237)	I_{FFL}	FIELD CURRENT at 100% load, amperes
		$I_{FFL} = (F_{FL})/(N_P) = (236)/(146a)$

(238) [illegible] FIELD [illegible] calculated [illegible] [illegible] expected temperature at 100% load.

$$\text{Field Volt.} = (I_{FFL})(R_{f\ hot}) = (237)(155)$$

(239) S_{FL} CURRENT DENSITY at 100% load amperes per square inch

$$\text{Current Density} = (I_{FFL}) / (a_{ci}) = (237) / (153)$$

(241) I^2R_R ROTOR I^2R at 100% load - The copper loss in the field winding is calculated with hot field resistance at expected temperature for 100% load condition. (watts)

$$\text{Rotor } I^2R = (I_{FFL})^2 (R_{f\ hot}) = (237)^2 (155)$$

(242) W_{TFL} STATOR TEETH LOSS at 100% load - The stator tooth loss under load increases over that of no load because of the parasitic fluxes caused by the ripple due to the rotor damper bar slot openings. (watts)

$$W_{TFL} = \left\{ 2 \left[.27 \frac{(X_d)}{100} \frac{(\%\ \text{Load})}{100} \right]^{1.8} + 1 \right\} (W_{TNL})$$

$$= \left\{ 2 \left[.27 \frac{(133)}{100} \frac{(\%\ \text{Load})}{100} \right]^{1.8} + 1 \right\} (184)$$

(243) W_{PFL} POLE FACE LOSS at 100% load (watts)

$$W_{PFL} = \left\{ \left[\frac{(K_{sc})(I_{PH}) \frac{(\%\ \text{Load})}{100} (n_s)}{(C)(F_g)} \right]^2 + 1 \right\} (W_{PNL})$$

$$= \left\{ \left[\frac{(243)(8)\ 1\ (30)}{(32)(96)} \right]^2 + 1 \right\} (186)$$

(K_{sc}) is obtained from Curve F-3

(244) W_{DFL} DAMPER LOSS at 100% load (watts)

$$W_{DFL} = \left\{ \left[\frac{(K_{sc})(I_{PH}) \frac{(\% \text{ Load})}{100} (I_s)}{(C)(F_g)} \right]^2 - 1 \right\} (W_{FNL})$$

$$= \left\{ \left[\frac{(244)(8)\ 1\ (30)}{(32)(96)} \right]^2 - 1 \right\} (193)$$

(K_{sc}) is obtained from Curve F-3

(245) I^2R_L STATOR I^2R at 100% load - The copper loss based on the resistance of the winding. Calculated at the maximum expected operating temperature. (watts)

$$I^2R_L = (m)(I_{PH})^2 (R_{SPH\,hot}) \frac{(\% \text{ Load})}{100}$$

$$= (5)(8)^2 (54)\ 1.$$

(246) -- EDDY LOSS - Stator I^2R loss due to skin effect (watts)

$$\text{Eddy Loss} = \left[\frac{(EF_{top}) + (EF_{bot})}{2} - 1 \right] (\text{Stator } I^2R)$$

$$= \left[\frac{(55) + (56)}{2} - 1 \right] (245)$$

(247) -- **TOTAL LOSSES** at 100% load - sum of all losses at 100% load

Total Losses = (Rotor I^2R) + (F & W) + (Stator Teeth Loss) + (Stator Core Loss) + (Pole Face Loss) + (Damper Loss) + (Stator I^2R) + (Eddy Loss)

= (241) + (183) + (242) + (185) + (243) + (244) + (245) + (246)

= watts

(248)	--	RATING IN KILOWATTS at 100% load
		$$\text{Rating} = 3(E_{PH})(I_{PH}) \quad (\text{P.F.}) \frac{(\%\ \text{Load})}{100}$$
		$$= 3(4)(8) \quad (9)(1.)$$
(249)	--	**RATING & Σ LOSSES** = (248) + (247) x 10^{-3}
(250)	--	**% LOSSES** = $\left[\Sigma \text{Losses} / (\text{Rating} + \Sigma \text{Losses})\right] 100$
		$$= \left[(247) \times 10^{-3} / (249)\right] 100$$
(251)	--	**% EFFICIENCY** = 100% - % Losses
		= 100% - (250)

Item(197a) through (251) are 100% load calculations. These items can be recalculated for any load condition by simply inserting the values that correspond to the % load being calculated. The factor $\frac{(\%\ \text{Load})}{100}$ takes care of (I_{PH}) as it changes with load.

Note that values for F & W (183) and W_C (Stator Core Loss) (185) do not change with load, therefore they can be calculated only once.

INPUT AUXILIARY DATA SHEET

Auxiliary information taken from the design manuals to be used in conjunction with input sheets for convenience.

A. All dimensions for lengths, widths, and diameters are to be given in inches.

B. Resistivity inputs, Items (141) and (151) are to be given in micro-ohm-inches.

The following items along with an explanation of each are tabulated here for convenience. For complete explanation of each item number, refer to design manuals.

Item No.	Explanation
(9)	Power factor to be given in per unit. For example for 90% P.F., insert .90.
(9a)	Adjustment Factor - For P.F. < .95 insert 1.0 For P.F. > .95 insert 1.05
(10)	Optional Load Point -- Where load data output is required at a point other than those given as standard on the input sheet. Example: For load data output at 155% load, insert 1.55.
(14)	Number of radial ducts in stator.
(15)	Width of radial ducts used in Item (14).
(18)	Magnetization curve of material used to be submitted as defined in Item (18).
(19)	Watts/Lb. to be taken from a core loss curve at the density given in Item (20) (Stator).
(20)	Density in kilolines/in^2. This value must correspond to density used to pick Item (19) usually use 77.4 KL/in^2.
(21)	Type of slot - For open slot Type A, insert 1.0. For partially open slot Type B with constant slot width, insert 2.0. For partially open slot Type C with constant tooth width, insert 3.0. For round slot Type D, insert 4.0. For additional information, refer to figure adjacent to input sheet which shows a picture of each slot.
(22)	For stator slot dimension - for dimensions that do not apply to the slot insert 0.0. Use Table below as guide for input.

Symbol	Item	Slot Type 1	2	3	4
b_o	(22)	0.0	*	*	*
b_1	↓	0.0	0.0	*	0.0
b_2	↓	0.0	0.0	*	0.0
b_3	↓	0.0	0.0	*	0.0
b_s	↓	*	*	✠	*
h_o	↓	0.0	*	*	*
h_1	↓	*	*	*	0.0
h_2	↓	*	0.0	0.0	0.0
h_3	↓	*	*	0.0	0.0
h_s	↓	*	*	*	*
h_t	↓	0.0	*	*	0.0
h_w	↓	0.0	*	*	0.0

* = insert actual value.

✠ = $b_s = \frac{b_1 + b_3}{2}$

Item No.	Explanation
(28)	Type of winding - for wye connected winding insert 1.0.
	for delta connected winding insert 0.0.
(29)	Type of coil - for formed wound (rect. wire), insert 1.0.
	for random wound (round wire) insert 0.0.
(30)	Slots spanned - Example - for slot span of 1-10, insert 9.0.
(33)	For round wire insert diameter. For rectangular wire insert wire width.
(34)	Strands per conductor in depth only.
(34a)	Total strands per conductor in depth and width.
(35)	Diameter of coil head forming pin. Insert .25 for stator O.D. < 8 inches;
	Insert .50 for stator O.D. > 8 in.
(37)	Use vertical height of strand for round wire, insert 0.0.
(38)	Distance between centerline of strands in depth.
(39)	Stator strand thickness -- use narrowest dimension of the two dimensions given for a rectangular wire. For round wire insert 0.0.
(40)	Stator slot skew in inches.
(42a)	Phase belt angle - for 60° phase belt, insert 60°.
	for 120° phase belt, insert 120°.
(48)	See explanation of items (71), (72), (73), (74) and (75). Same applies here.
(87)	When no load saturation output data is required at various voltages, insert 1.0.
	When no load saturation inform..ion is not required, insert 0.0.
(137)	Damper bar thickness -- use damper bar slot height for rectangular bar. For round bar insert 0.0.
(138)	Number of damper bars per pole.
(140)	Damper bar pitch in inches.
(148)	For round wire insert diameter. For rectangular wire insert wire width.
(149)	For rectangular wire insert wire thickness. For round wire insert 0.0.
(187)	Pole face loss factor. For rotor lamination thickness .028 in. or less, insert 1.17.
	For rotor lamination thickness .029 in. to .063 in. insert 1.75.
	For rotor lamination thickness .064 in. to .125 insert 3.5.
	For solid rotor insert 7.0.
(71) (72) (73) (74)	If the values of these constants are available, insert the actual number. If they are not available, insert 0.0 and the computer will calculate the values and record them on the output.

NON-SALIENT-POLE DESIGN (INPUT)

MODEL ______________ EWO ______________ DESIGN NO.(1) ______________ BY ______________

	No.	Symbol	Item		
PARAMETERS	(2)	KVA	GENERATOR KVA		
	(3)	E	LINE VOLTS		
	(4)	E_{ph}	PHASE VOLTS		
	(5)	m	PHASES		
	(5a)	f	FREQUENCY		
	(6)	p	POLES		
	(7)	RPM	RPM		
	(8)	I_{ph}	PHASE CURRENT		
	(9)	PF	POWER FACTOR		
	(10)		OPTIONAL LOAD POINT		
STATOR STACK	(11)	d	STATOR I.D.		
	(12)	D	STATOR O.D.		
	(13)	ℓ	GROSS CORE LENGTH		
	(14)	n_v	NO. OF DUCTS		
	(15)	b_v	WIDTH OF DUCT		
	(16)	K_i	STACKING FACTOR (STATOR)		
	(19)	k	WATTS/LB.		
	(20)	B	DENSITY		
STATOR SLOT	(21)		TYPE OF SLOT		
	(22)	b_o	SLOT OPENING		
	(22)	b_1	SLOT WIDTH TOP		
	(22)	b_2			
	(22)	b_3			
	(22)	b_s	SLOT WIDTH		
	(22)	h_o			
	(22)	h_1			
	(22)	h_2			
	(22)	h_3			
	(22)	h_s	SLOT DEPTH		
	(22)	h_t			
	(22)	h_w			
	(23)	Q	NO. OF SLOTS		
STATOR WINDING	(28)		TYPE OF WDG.		
	(29)		TYPE OF COIL		
	(30)	n_s	CONDUCTORS/SLOT		
	(31)	y	SLOTS SPANNED		
	(32)	c	PARALLEL CIRCUITS		
	(33)		STRAND DIA. OR WIDTH		
	(34)	N_{st}	STRANDS/CONDUCTOR		
	(34a)	N'_{st}	STRANDS/CONDUCTOR		
	(39)		STATOR STRAND T'KNS		
	(35)	d_b	DIA. OF PIN		
	(36)	ℓ_{e2}	COIL EXT. STR. PORT		
	(37)	h_{st}	UNINS. STRD. HT.		
	(38)	h'_{st}	DIST. BTWN. C_L OF STD.		
	(42a)		PHASE BELT/ANGLE		
	(40)	τ_{sk}	STATOR SLOT SKEW		
	(50)	X_s °C	STATOR TEMP °C		
	(51)	ρ_s	RES'TVY STA. COND. - 20° C		
	(59)	g_{min}	MINIMUM AIR GAP		

	Item	No.	Symbol	
	FUND/MAX OF FIELD FLUX	(71)	C_1	CONSTAN
	WINDING CONSTANT	(72)	C_w	
	POLE CONST.	(73)	C_p	
	END EXTENSION ONE TURN	(48)	L_E	
	DEMAGNETIZATION FACTOR	(74)	C_m	
	TYPE ROTOR 1, 2	*		ROTOR
	SLOTS PUNCHED	(300)	Q'_r	
	SLOTS WOUND	(301)	Q'_r	
	SLOTS IN POLE CENTER	(302a)	N_{rc}	
	WIDTH OF SLOT OPENING	(303)	b_{rc}	
	HEIGHT OF SLOT OPENING	(303)	h_{r2}	
	SLOT DEPTH BELOW WEDGE	(303)	h_{r1}	
	SLOT WIDTH	(303)	b_r	
	SLOT DEPTH	(303)	h_r	
	SLOT PITCH	(304)	t_{rs}	
	ROTOR STACK LENGTH	(305)	ℓ_r	
	ROTOR STACKING FACTOR	(16)	K_i	
	ROTOR DIAMETER	(11a)	d_r	
	ROTOR I.D. (PCHGS.)	(314a)	d_s	
	HEIGHT VENT HOLES	(314b)	b_{rh}	
	WEIGHT OF ROTOR IRON	(157)	(-)	
	POLE FACE LOSS FACTOR	(187)	(K1)	
	NO. OF FIELD TURNS/POLE	(146a)	N_p	FIELD
	MEAN LENGTH OF FLD. TURN	(147)	ℓ_{tf}	
	FLD. COND. DIA. OR WIDTH	(148)		
	FLD. COND. THICKNESS	(149)		
	FLD. TEMP IN C	(150)	X_f °C	
	RESISTIVITY OF FIELD COND - 20°	(151)	ρ_f	
	NO LOAD SAT.	(87)		
	FRICTION & WINDAGE	(183)	(F&W)	
	ROTOR LAM MTR'L	(18)		MTR'L
	STATOR LAM. MTR'L (CURVE)	(18)		

STATOR SLOT	ROTOR SLOT

* SLOTTED POLE-CENTER 2
SOLID POLE-CENTER 1

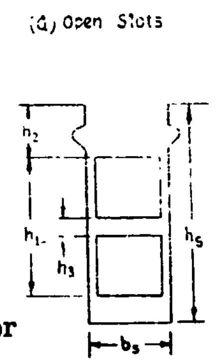
REMARKS :

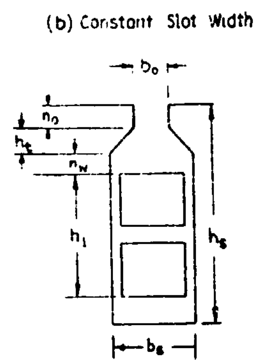
H-01

REV. A

TYPE 1

(Type 5 is an open slot with 1 conductor per slot)



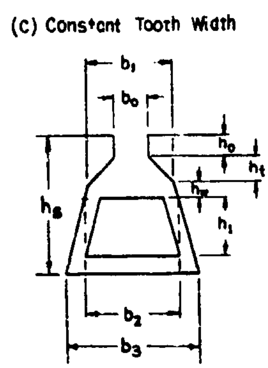


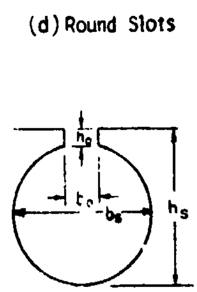
TYPE 2

TYPE 3

b_s for type 3 is

$$b_s = \left(\frac{b_2 + b_3}{2}\right)$$





TYPE 4

SUMMARY OF DESIGN CALCULATIONS – NON-SALIENT – POLE (OUTPUT)

MODEL ______ ______ EWO ______ DESIGN NO. ______

	(17) (ℓ_s)	SOLID CORE LENGTH			CARTER COEFFICIENT	(67) (K_s)	GAP
	(24) (h_c)	DEPTH BELOW SLOT			AIR GAP AREA	(68) (–)	
	(26) (τ_s)	SLOT PITCH			AIR GAP PERM	(70c) (λ_a)	
	(27) (τ_s 1/3)	SLOT PITCH 1/3 DIST. UP			EFFECTIVE AIR GAP	(69) (g_e)	
S[illegible]R	(42) (K_{sk})	SKEW FACTOR			FUND/MAX OF FLD. FLUX	(71) (C_1)	CONSTANTS
	(43) (K_d)	DIST. FACTOR			WINDING CONST.	(72) (C_w)	
	(44) (K_p)	PITCH FACTOR			POLE CONST.	(73) (C_p)	
	(45) (n_e)	EFF. CONDUCTORS			END. EXT. ONE TURN	(48) (L_E)	
	(46) (a_c)	COND. AREA			DEMAGNETIZING FACTOR	(74) (C_M)	
	(47) (S_s)	CURRENT DENSITY (STA.)			AMP COND/IN	(128) (A)	REACTANCE
	(49) (ℓ_t)	1/2 MEAN TURN LENGTH			REACTANCE FACTOR	(129) (X)	
	(53) (R_{ph})	COLD STA. RES. @ 20° C			LEAKAGE REACTANCE	(130) (X_q)	
	(54) (R_{ph})	HOT STA. RES. @ X °C			REACTANCE OF	(131) (X_{ad})	
	(55) (EF_{top})	EDDY FACTOR TOP			ARMATURE REACTION		
	(56) (EF_{bot})	EDDY FACTOR BOT.			SYN REACT DIRECT AXIS	(133) (X_d)	
	(62) (λ_i)	STATOR COND. PERM.			FIELD LEAKAGE REACT	(160) (X_f)	
	(64) (λ_e)	END PERM.			FIELD SELF INDUCTANCE	(161) (L_f)	
	(65) ( )	WT. OF STA COPPER			UNSAT. TRANS. REACT	(166) (X'_{du})	
	(66) ( )	WT. OF STA IRON			SAT. TRANS. REACT	(167) (X'_d)	
[illegible]TOR	(312b) (λ_{rs})	ROTOR SLOT LEAK PER			SUB. TRANS. REACT	(166) (X''_d)	
	(153) (a_{CF})	FLD. COND. AREA			NEG SEQUENCE REACT	(170) (X_2)	
	(154) (R_F)	COLD FLD RES @ 20° C			ZERO SEQUENCE REACT	(172) (X_0)	
	(155) (R_F)	HOT FLD RES. @ X° C			TOTAL FLUX	(88) (ϕ_t)	MAGNETIZATION
	(156) ( )	WT OF FLD COPPER			FLUX PER POLE	(92) (ϕ_p)	
	(157) ( )	WT OF ROTOR IRON			GAP DENSITY	(95) (B_g)	
	(145) (V_r)	PERIPHERAL SPEED			TOOTH DENSITY	(91) (B_t)	
TIME CONSTAN[illegible]	(176) (T_{do})	OPEN CIR. TIME CONST.			CORE DENSITY	(94) (B_c)	
	(177) (T_a)	ARM TIME CONST.			TOOTH AMPERE TURNS	(97) (F_t)	
	(178) (T'_d)	TRANS TIME CONST.			CORE AMPERE TURNS	(98) (F_c)	
	(179) (T''_d)	SUB TRANS TIME CONST.			GAP AMPERE TURNS	(96) (F_g)	
	(180) (F_{sc})	SHORT CIR NI					
	(181) (SCR)	SHORT CIR RATIO					

		PERCENT LOAD	0		100	150	200	OPTIONAL
VARIABLE LOAD	(ϕ_{gs})	(312) LEAK FLUX		(ϕ_{fls}) (312a)				
	(ϕ_{rc})	(313) FLUX IN P.C.		(ϕ_{rcl}) (318)				
	(B_{pd})	(314) POLE DENSITY		(B_{pcl}) (319)				
	(B_{rc})	(315) ROTOR CORE DENSITY		(B_{pcl}) (321)				
	(F_{nl})	(127) TOTAL NI		(F_{fl}) (236)				
	(I_{nl})	(127a) FIELD AMPS		(I_{fl}) (237)				
	(S_F)	(127c) CUR. DENS. (FLD)		(S_{fl}) (239)				
	(E_F)	(127b) FIELD VOLTS		(E_{fl}) (238)				
	(I^2R_r)	(182) ROTOR LOSS		(I^2R_r) (241)				
	(F&W)	(183) F&W LOSS		(F&W) (183)				
	(W_{tnl})	(184) STA TOOTH LOSS		(W_{tnl}) (242)				
	(W_c)	(185) STA CORE LOSS		(W_c) (185)				
	(W_{pnl})	(186) POLE FACE LOSS		(W_{pfl}) (243)				
	(I^2R_s)	(194) STATOR CU LOSS		(I^2R_s) (245)				
	(–)	(195) EDDY LOSS		(–) (246)				
	(–)	(196) TOTAL LOSSES		(–) (247)				
	(–)	(–) RATING (KW)		(–) (248)				
	(–)	(–) RATING&LOSSES		(–) (249)				
	(–)	(–) PERCENT LOSSES		(–) (250)				
	(–)	(–) PERCENT EFF.		(–) (251)				

DESIGNER ______

DATE ______

REV. A

NO LOAD SATURATION OUTPUT SHEET

NON-SALIENT POLE, WOUND-POLE

ITEMS / VOLTS	(3) (E) VOLTS	(96) (F_g) AIR GAP A.T.	(91) (B_t) TOOTH DENSITY	(97) (F_t) TOOTH A.T.	(94) (B_c) CORE DENSITY	(98) (F_c)
	(98a) (F_s) STATOR A.T.	(312) ϕ_{Ls} LEAKAGE FLUX	(313) ϕ_{rc} TOTAL FLUX/POLE	(314) B_{pc} POLE DENSITY	(315) (F_{pc}) POLE A.T.	(127) (F_{nl}) TOTAL A.T. (N.L
80%						
90%						
100%						
110%						
120%						
130%						
140%						
150%						
160%						

NON-SALIENT POLE, WOUND-POLE A. C. GENERATOR
DESIGN COMPUTER MANUAL

(1)	--	DESIGN NUMBER
(2)	KVA	GENERATOR KVA
(3)	E	LINE VOLTS
(4)	E_{PH}	PHASE VOLTS
(5)	m	PHASES
(5a)	f	FREQUENCY
(6)	P	POLES
(7)	RPM	SPEED
(8)	I_{PH}	PHASE CURRENT
(9)	P. F.	POWER FACTOR
(9a)	K_c	ADJUSTMENT FACTOR
(10)	--	LOAD POINTS
(11)	d	STATOR PUNCHING I.D.
(11a)	d_r	ROTOR O.D.
(12)	D	PUNCHING O.D.
(13)	ℓ	GROSS STATOR CORE LENGTH
(14)	n_v	RADIAL DUCTS
(15)	b_v	RADIAL DUCT WIDTH
(16)	K_1	STACKING FACTOR
(17)	ℓ_s	SOLID CORE LENGTH
(18)		MATERIAL

(19)	k	WATTS/LB
(20)	B	DENSITY
(21)		TYPE OF STATOR SLOT
(22)		ALL SLOT DIMENSIONS
(23)	Q	STATOR SLOTS
(24)	h_c	DEPTH BELOW SLOTS
(25)	q	SLOTS PER POLE PER PHASE
(26)	τ_s	STATOR SLOT PITCH
(27)	τ_s 1/3	STATOR SLOT PITCH
(28)	--	TYPE OF WINDING
(29)	--	TYPE OF COIL
(30)	n_s	CONDUCTORS PER SLOT
(31)	y	THROW
(31a)		PER UNIT OF POLE PITCH SPANNED
(32)	C	PARALLEL PATHS
(33)	--	STRAND DIA. OR WIDTH
(34)	N_{ST}	NUMBER OF STRANDS PER CONDUCTOR IN DEPTH
(34a)	N'_{ST}	NUMBER OF STRANDS PER CONDUCTOR
(35)	d_b	DIAMETER OF BENDER PIN
(36)	ℓ_{e2}	COIL EXTENSION BEYOND CORE
(37)	h_{ST}	HEIGHT OF UNINSULATED STRAND
(38)	h'_{ST}	DISTANCE BETWEEN CENTERLINES OF STRANDS IN DEPTH

(39)	--	STATOR COIL STRAND THICKNESS
(40)	τ_{SK}	SKEW
(41)	τ_P	POLE PITCH
(42)	K_{SK}	SKEW FACTOR
(42a)		PHASE BELT ANGLE
(43)	K_d	DISTRIBUTION FACTOR
(44)	K_p	PITCH FACTOR
(45)	n_e	TOTAL EFFECTIVE CONDUCTORS
(46)	a_c	CONDUCTOR AREA OF STATOR WINDING
(47)	S_S	CURRENT DENSITY
(48)	L_E	END EXTENSION LENGTH
(49)	ℓ_t	1/2 MEAN TURN
(50)	$X_S\ ^\circ C$	STATOR TEMP °C
(51)	ρ_s	RESISTIVITY OF STATOR WINDING
(52)	$\rho_{S\,(hot)}$	RESISTIVITY OF STATOR WINDING
(53)	R_{SPH} (cold)	STATOR RESISTANCE/PHASE
(54)	R_{SPH} (hot)	STATOR RESISTANCE/PHASE
(55)	EF (top)	EDDY FACTOR TOP
(56)	EF (bot)	EDDY FACTOR BOTTOM

(57)	b_{tm}	STATOR TOOTH WIDTH
(57a)	$b_{t\,1/3}$	STATOR TOOTH WIDTH
(58)	b_t	TOOTH WIDTH AT STATOR I.D. IN INCHES
(59)	g	MAIN AIR GAP IN INCHES
(60)	C_X	REDUCTION FACTOR used in calculating (62)
(61)	K_X	Factor used in calculating (60)
(62)	λ_i	SLOT LEAKAGE PERMEANCE
(63)	K_E	LEAKAGE REACTIVE FACTOR
(64)	λ_E	END WINDING FLUX LEAKAGE PERMEANCE
(65)	--	WEIGHT OF COPPER
(66)	--	WEIGHT OF STATOR IRON
(67)	K_s	CARTER COEFFICIENT
(68)	A_g	MAIN AIR GAP AREA
(69)	g_e	EFFECTIVE GAP - The effective single air gap.
		$g_e = K_s K_r g$ (for rotors with slotted pole centers) = (67)(308)(
		$g_e = K_s g$ (for rotors with solid pole centers) = (67)(59)

(70c)	λ_a	AIR GAP PERMEANCE
(71)	C_1	THE RATIO OF MAXIMUM FUNDAMENTAL of the field form to the actual maximum of the field form.

FOR A ROTOR WITH SOLID CENTER SECTION

$$C_1 - \frac{4}{\pi} \cos\left(\frac{\pi \alpha}{2}\right) \left[\frac{K_r - 1}{K_r}\right] + \frac{8}{\pi^2 Kr \alpha} \sin\left(\frac{\pi \alpha}{2}\right)$$

$$C_1 = \frac{4}{\pi} \cos \frac{\pi (302)}{2} \left[\frac{(308) - 1}{(308)}\right] + \frac{8}{\pi^2 (308)(302)} \sin \frac{\pi (302)}{2}$$

FOR A ROTOR WITH SLOTTED CENTER SECTION - When the center is slotted instead of solid the K_r applies to the complete rotor. Therefore, by making K_r equal to unity in the above equation we will get an answer that is independent of the effect of rotor slots and

$$C_1 = \frac{8}{\pi^2 \alpha} \sin\left(\frac{\pi \alpha}{2}\right) = \frac{8}{\pi^2 (302)} \sin \left(\frac{\pi (302)}{2}\right)$$

When using this value of C_1, it is necessary to include K_r in g_e and

$$g_e = K_r K_s g = (69) = (67)(308)(59)$$

(72)	C_W	WINDING CONSTANT

(73) C_p **POLE CONSTANT** - The ratio of the average to the maximum value of the field form.

BASED ON A ROTOR WITH A SOLID CENTER SECTION

$$C_p = 1 - \alpha + \frac{\alpha}{2K_r} = 1 - (302) + \frac{(302)}{2(308)}$$

BASED ON A ROTOR WITH SLOTTED CENTER SECTION

When the center is slotted instead of solid K_r is included in the effective gap and K_r becomes unity in the C_p equation.

$$C_p = 1 - \alpha + \frac{\alpha}{2} = 1 - \frac{\alpha}{2} = 1 - \frac{(302)}{2}$$

(74) C_M **DEMAGNETIZING FACTOR**

$$C_M = \frac{\pi^2}{8} \; \frac{\alpha}{\sin \frac{\pi\alpha}{2}} = \frac{\pi^2}{8} \; \frac{(302)}{\sin \frac{\pi(302)}{2}}$$

Ref: Quarterly report page 80 (Appendix).

(87) -- **NO LOAD SATURATION NOTE**

(88) ϕ_T **TOTAL FLUX IN KILOLINES**

(91) B_t **TOOTH DENSITY IN KILOLINES/in^2**

(92) ϕ_p **FLUX PER POLE IN KILOLINES**

(94) B_c **CORE DENSITY IN KILOLINES/in^2**

(95) B_g **GAP DENSITY IN KILOLINES/in^2**

(96)	F_g	AIR-GAP AMPERE-TURNS
(97)	F_T	STATOR TOOTH AMPERE TURNS
(98)	F_c	STATOR CORE AMPERE-TURNS
(98a)	F_S	STATOR AMPERE TURNS
(104a)	F_R	ROTOR AMPRE TURNS OR POLE AMPERE TURNS at no-load. The ampere turns per pole required to force the flux through the pole center and rotor core at no-load, rated voltage. The core density should be low enough at no-load to ignore. $F_R = F_{PC} + F_{rc} = (316) + (317)$
(127)	F_{NL}	THE TOTAL NO-LOAD AMPERE TURNS PER POLE REQUIRED TO PRODUCE RATED VOLTAGE AT NO-LOAD $F_{NL} = F_g + F_s + F_R = (96) + (98a) + (104a)$
(127a)	I_{FNL}	FIELD CURRENT AT NO-LOAD
(127b)	E_F	FIELD VOLTS AT NO-LOAD
(127c)	S_F	CURRENT DENSITY AT NO-LOAD AMPS/IN^2 IN FIELD CONDUCTOR
(128)	A	AMPERE CONDUCTORS PER INCH
(129)	X	REACTANCE FACTOR
(130)	X_ℓ	LEAKAGE REACTANCE
(131)	X_{ad}	REACTANCE DIRECT AXIS REACTANCE OF ARMATURE REACTION
(133)	X_d	SYNCHRONOUS REACTANCE $X_d = X_\ell + X_{ad} = (130) + (131)$
(145)	V_r	PERIPHERAL SPEED OF ROTOR

(146a)	N_p	TURNS PER POLE - The total number of field turns per pole. $$N_p = \frac{n_r Q_r}{2p} = \frac{(306)(301)}{2(6)}$$
(147)	ℓ_{tr}	MEAN TURN - The mean length of rotor turn. This value must be calculated from a layout of the rotor winding.
(148)		FIELD CONDUCTOR DIAMETER OR WIDTH (INCHES)
(149)		FIELD CONDUCTOR THICKNESS (INCHES) Set = 0 for round
(150)	X_f °C	FIELD TEMP. IN °C
(151)	ρ_f	RESISTIVITY OF ROTOR WINDING AT 20°C OHM INCHES x 10^{-6} Refer to item (51) for conversion factors.

(152)	ρ_f	<u>RESISTIVITY OF ROTOR WINDING AT X_f°C</u>
(153)	a_{cf}	<u>AREA OF CONDUCTOR</u> - The actual area of the conductor taking into account the corner radius.
(154)	R_f (cold)	<u>COLD FIELD RESISTANCE AT 20°C</u>
(155)	R_f (hot)	<u>HOT FIELD RESISTANCE AT X°C</u>
(156)		<u>WEIGHT OF COPPER</u> - The weight in lbs. of the field winding.
		Lbs. $= .321\ N_p\ P \ell_{tr}\ a_{cr} = .321\ (146a)(6)(147)(153)$
(157)		<u>WEIGHT OF IRON</u> - The weight in lbs. of the rotor iron.
		$\# = .283 \left[\pi(d_r - h_r) - Q_r\ b_r\right] \ell_{rs}\ h_r +$
		$+\ .283\ \pi\ (d_s + h'_{rc})\ h'_{rc}\ \ell_{rs}$
		$= .283 \left\{\pi\left[(11a) - (303)\right] - (301)(303)\right\}(305a)(303) +$
		$.283\ \pi\left[(314a) + (330)\right]\ (330)(305a)$
		For slotted pole centers $Q_r = Q'_r$
		$(300) = (301)$

(160)	X_F	FIELD LEAKAGE REACTANCE - The leakage reactance of the field winding. $X_F = X \frac{4}{\pi} C_M{}^2 \lambda F, = (129) \frac{4}{\pi} (74)^2 (332)$
(161)	L_F	FIELD SELF INDUCTANCE - The total self inductance of the field winding. $L_F = \frac{N_P^2 \; p \, \ell r}{10^8} \left[C_F \left(3.19 \frac{\tau_p}{g_e}\right) + \lambda_F \right]$ (Henries) $= \frac{(146a)^2(6)(305)}{10^8} \left[(331)\, 3.19 \frac{(41)}{(69)} + (332) \right]$
(163)	X_{Dd}	DAMPER LEAKAGE REACTANCE - The leakage reactance of the effective damper and eddy current circuits. $X_{Dd} = X \lambda_{Dd}$ $\lambda_{Dd} = \frac{3.19p}{d} (g + \delta_d + h_{r2})$ where δ_d = depth of penetration factor $\delta_d = 0.47 \sqrt{\frac{400}{f}}$

$$\lambda_{Dd} = \frac{3.19\,(6)}{(11)} \left\{ (59) + (163) + (303) \right\}$$

(166)	X'_{du}	UNSATURATED TRANSIENT REACTANCE - The transient reactance due to the field winding, assuming unsaturated conditions. $$X'_{du} = X_{\ell} + X_F\left(\frac{X_{ad}}{X_F + X_{ad}}\right) = (130) + (160)\left(\frac{(131)}{(160) + (131)}\right)$$
(167)	X'_d	SATURATED TRANSIENT REACTANCE - The transient reactance due to the field winding assuming normally saturated conditions. $$X'_d = 0.88\ X'_{du} = 0.88\ (166)$$
(168)	X''_d	SUBTRANSIENT REACTANCE - The subtransient reactance due to the eddy current circuits. $$X''_d = X_{\ell} + X_{D\ell} = (130) + (163)$$
(170)	X_2	NEGATIVE SEQUENCE REACTANCE - The reactance due to the field which rotates at synchronous speed in a direction opposite to that of the rotor. $$X_2 = X''_d = (168)$$

(172) X_o **ZERO SEQUENCE REACTANCE** - The reactance drop across any one phase (star connected) for unit zero sequence current in each of the phases. The machine must be star connected for otherwise no zero sequence current can flow and the term has no significance.

$$X_o = X\left[\frac{K_{xo}}{K_{x1}}\left(\lambda_i + \lambda_{Dd}\right) + \frac{20(h_1 + 2h_3)}{12 mq K_p^2 K_d^2 b_s} + 0.2\lambda_E\right]$$

$$= (129)\left\{\frac{(173)}{(174)}\left[(62) + (163)\right] + \frac{1.667\left[(22) + 2(22)\right]}{(5)(25)(44)^2(43)^2(22)} + .2(64)\right\}$$

(173) K_{xo}

If (30) = 1 Then $K_{xo} = 1$

If (30) $\neq$ 1 Then $K_{xo} = \dfrac{3(\gamma)}{(m)(q)} - 2$

$$= \frac{3(31)}{(5)(25)} - 2$$

(174) K_{x1}

If (30) = 1 Then $K_{x1} = 1$

If (30) $\neq$ 1 Then:

$$K_{x1} = \left[\frac{3(\gamma)}{4(m)(q)} + \frac{1}{4}\right] = \left[\frac{3(31)}{4(5)(25)} + \frac{1}{4}\right] \quad \text{If } (31a) \geq .667$$

$$K_{x1} = \left[\frac{3(\gamma)}{4(m)(q)} - \frac{1}{4}\right] = \left[\frac{3(31)}{4(5)(25)} - \frac{1}{4}\right] \quad \text{If } (31a) < .667$$

(176)	T'_{do}	OPEN CIRCUIT TIME CONSTANT
(177)	T_a	ARMATURE TIME CONSTANT
(178)	T'_d	TRANSIENT TIME CONSTANT
(179)	T''_d	SUBTRANSIENT TIME CONSTANT
(180)	F_{sc}	SHORT CIRCUIT AMPERE TURNS
(181)	S_{CR}	SHORT CIRCUIT RATIO
(182)	I^2R_R	ROTOR I^2R AT NO LOAD
(183)	F & W	FRICTION & WINDAGE LOSS

(184)	W_{TNL}	<u>STATOR TEETH LOSS AT NO LOAD</u>
(185)	W_c	<u>STATOR CORE LOSS</u>
(186)	W_{NPL}	<u>POLE FACE LOSS AT NO LOAD</u>
(196)		<u>TOTAL LOSSES AT NO LOAD</u>

Rotor I^2R + F & W + Stator Teeth Losses + Stator Core Loss + Pole Face Loss

= (182) + (133) + (184) + (185) + (186)

(198) e_d The voltage that would be generated at no load and no saturation -- the air gap voltage behind the synchronous reactance.

$$e_d = \cos(\mathcal{E}) + \frac{(X_d)}{100} \sin(\psi)$$

$$= \cos(198) + \frac{(133)}{100} \sin(198)$$

Where $$\psi = \tan^{-1}\left[\frac{\sin(\Theta) + \frac{X_d}{100}}{\cos\Theta}\right]$$

$$= \tan^{-1}\left[\frac{\sin(198) + \frac{(133)}{100}}{\cos(198a)}\right]$$

(198a) Θ <u>POWER FACTOR ANGLE</u>

$$= \cos^{-1}\left[(PF)\right]$$

$$= \cos^{-1}\left[(9)\right]$$

Where $\mathcal{E} = (\psi) - (\Theta) = (198) - (198a)$

(236)	F_{FL}	TOTAL AMPERE TURNS PER POLE REQUIRED @100% LOAD $F_{FL} = e_d F_g + \left[\left(1 + \cos\theta\right) F_T\right] + F_c + F_{PCL} + F_{rcL}$ $= (198)(96) + (97)\left[1 + \cos(198a)\right] + (98) + (320) + (322)$
(237)	I_{FFL}	FIELD CURRENT @100% LOAD $I_{FFL} = \dfrac{F_{FL}}{N_P} = \dfrac{(236)}{(146a)}$
(238)	E_{FFL}	FIELD VOLTS @100% LOAD

(239)		CURRENT DENSITY IN FIELD CONDUCTORS AT 100% LOAD
(241)	I^2R_R	ROTOR I^2R AT 100% LOAD
(242)	W_{TFL}	STATOR TEETH LOSS AT 100% LOAD
(243)	W_{PFL}	POLE FACE LOSS AT 100% LOAD
(244)	W_{DFL}	DAMPER LOSS AT 100% LOAD
(245)	I^2R	STATOR I^2R AT 100% LOAD
(246)		EDDY LOSS AT 100% LOAD
(247)		TOTAL LOSSES AT 100% LOAD
(248)		RATING IN WATTS AT 100% LOAD
(249)		KW RATING PLUS LOSSES
(250)		% LOSSES
(251)		EFFICIENCY

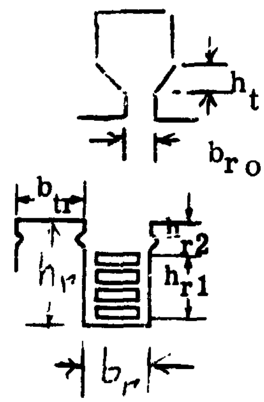
(300) Q'_r **SLOTS PUNCHED** - The total number of slots punched in the rotor. If the rotor is built with a solid pole center section Q'_r is the number of slot pitches on the rotor circumference.

(301) Q_r **SLOTS WOUND** - The total number of slots that are wound.

(302) α **RATIO OF SLOTS WOUND TO SLOTS PUNCHED**

$$\alpha = \frac{Q_r}{Q'_r} = \frac{(301)}{(300)}$$

(302a) N_{rc} **NO. OF SLOTS IN POLE CENTER**



(303) — **SIZE SLOTS** - The width of the rotor slot (b_r) and the depth of the rotor slot (h_r).

(304) τ_{rs} **TOOTH PITCH** - The rotor slot pitch at the rotor diameter.

$$\tau_{rs} = \frac{\pi d_r}{Q'_r} = \frac{\pi(110)}{(300)}$$

(305) ℓ_r **CORE LENGTH** - The overall length of the rotor core.

(305a) ℓ_{rs} **SOLID LENGTH OF ROTOR CORE**

$$\ell_{rs} = K_1 \ell_r = (16)(305)$$

(306) n_r **CONDUCTORS PER SLOT** - The number of rotor conductors per slot.

(307) X_p **POTIER REACTANCE** - The reactance determined by the Potier triange.

$$X_p = X_{\ell} + \left[\frac{F_R}{F_s + F_R} \right] X_{Fs} = (130) + \left[\frac{(104a)\ (307)}{(98a) + (104a)} \right]$$

$$X_{Fs} = \left[\frac{\lambda_{rs}}{\frac{2d}{p\, g_e} + \lambda_{rs}} \right] (X_d)$$

$$= \left[\frac{(312a)}{\frac{2(11)}{(6)(69)} + (312b)} \right] (133)$$

(308) K_r CARTER'S COEFFICIENT ROTOR - The Carter coefficient for the rotor slots.

For open slots -

$$K_r = \frac{t_{rs}\ (5g + b_r)}{t_{rs}\ (5g + b_r) - b_r^2} = \frac{(304) \left[5(59) + (303) \right]}{304 \left[5(59) + (303) \right] - (303)^2}$$

For partially closed slots -

$$K_r = \frac{t_{rs}\ (4.44g + 0.75\ b_{ro})}{t_{rs}\ (4.44g + 0.75\ b_{ro}) - b_{ro}^2} =$$

$$\frac{(304) \left[4.44\ (59) + 0.75\ (303) \right]}{(304) \left[4.44(59) + 0.75\ (303) \right] - (303)^2}$$

(311) ϕ_{gp}

FLUX IN POLE CENTER - The portion of the total flux in each pole center.

$$\phi_{gp} = \left[\frac{Q'_r - Q + p}{Q'_r}\right] \frac{\phi_T}{p} =$$

$$\left[\frac{(300) - (301) + (6)}{(300)}\right] \frac{(88)}{(6)}$$

(312) $\phi_{\ell s}$

LEAKAGE FLUX - The rotor slot leakage flux in Kilolines in each pole center.

$$\phi_{\ell s} = \frac{(F_g + F_s)\ell_r \lambda_{rs}}{1000} =$$

$$\left[(96) + (98a)\right] (305)\ (312b)\ 10^{-3}$$

(312a $\phi_{\ell s}$

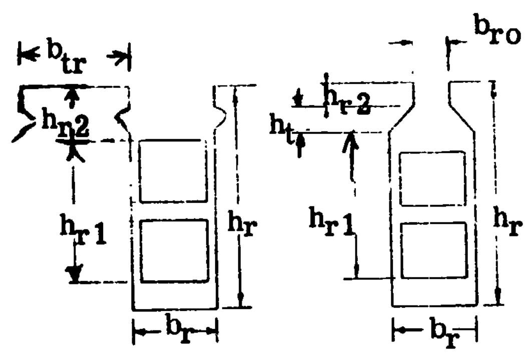
SLOT LEAKAGE FLUX IN EACH POLE CENTER AT 100% LOAD

$$\phi_{\ell\ell s} = \phi_{\ell s}\left\{\frac{(e_d)(F_g) + \left[1 + \cos(\theta)\right](F_T) + (F_C)}{(F_g) + (F_T) + (F_C)}\right\}$$

$$= (312)\left\{\frac{(198)(96) + \left[1 + \cos(198a)\right](97) + (98)}{(96) + (97) + (98)}\right\}$$

(312b)	λ_{rs}	The rotor slot leakage permeance per inch of stator length.

For either open or semi-closed slots



$$\lambda_{rs} = \frac{12.76P}{Q_r}\left[\frac{h_{r2}}{b_{ro}} + \frac{2h_t}{b_{ro} + b_r} + \frac{.35(\tau_{rs} - b_{ro})}{\tau_{rs}} + \frac{g}{2\tau_{rs}}\right]$$

$$\lambda_{rs} = \frac{12.76(3)}{(301)}\left[\frac{(303)}{(303)} + \frac{2(303)}{(303) + (303)} + \frac{.35\left[(304) - (303)\right]}{(304)} + \frac{(59)}{2(304)}\right]$$

(313)	ϕ_{rc}	TOTAL FLUX IN THE POLE CENTER

$$\phi_{rc} = \phi_{gp} + \phi_{\ell s}$$

$$\phi_{rc} = (311) + (312)$$

(314) B_{pc} **CENTER SECTION DENSITY** - The flux density of the center section of the rotor at a section half way down the rotor tooth. @ No Load

$$B_{pc} = \frac{\phi_{rc}}{b_p \ell_{rs}} = \frac{(313)}{(314)\ (305a)}$$

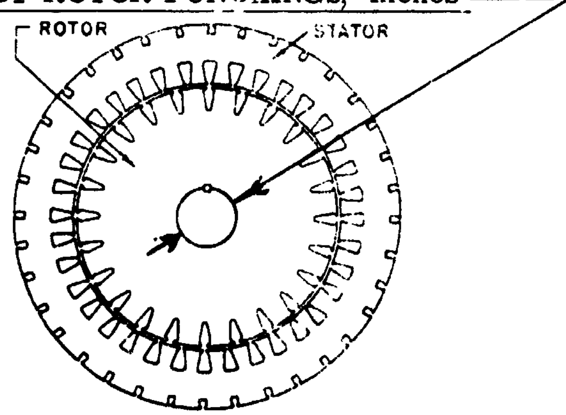
$$\text{where } bp = \left[\frac{\pi(d_r - h_r)}{p}\right] \left[\frac{Q'_r - Q_r - p}{Q_r}\right] - br \quad \text{(solid centers)}$$

$$b_p = \left[\frac{\pi(11a) - (303)}{(6)}\right] \left[\frac{(300) - (301) - (6)}{(301)}\right] - (303)$$

$$bp = \left[\frac{\pi(d_r - h_r)}{p}\right] \left[\frac{Q'_r - Q_r - p}{Q'_r}\right] - (n_{rc} - 1)b_r \quad \text{(slotted centers)}$$

$$b_p = \left[\frac{\pi(11a) - (303)}{(6)}\right] \left[\frac{(300) - (301) - (6)}{(301)}\right] - \left[(302a) - 1\right](303)$$

(314a) d_s INNER DIAMETER OF ROTOR PUNCHINGS, inches



(314b)	b_{rh}	HEIGHT OF VENTILATING HOLES IN ROTOR CORE AREA
(315)	B_{rc}	CORE DENSITY - The flux density in the rotor core @ No Load

$$B_{rc} = \frac{\phi_{rc}}{2h_{rc}\ell_{rs}} = \frac{(313)}{2\,(315)\,(305a)}$$

$$\text{where } 2h_{rc} = d_r - 2h_r - d_s - 2b_{rh}$$

$$= (11a) - 2(303) - (314a) - 2(314b)$$

(316)	F_{PC}	AMPERE TURN DROP IN THE POLE CENTER AT NO LOAD

$$F_{PC} = h_r \left[\text{NI/in. @ } B_{PC} \right]$$

$$= (303) \left[\begin{array}{l} \text{Look up rotor magnetization curve} \\ \text{given in (18) at density (314).} \end{array} \right]$$

(317)	F_{rc}	AMPERE TURN DROP IN THE ROTOR CORE

$$F_{rc} = \frac{\pi (d_s + h_{rc})}{4p} \left[\text{NI/in. @ density } B_{rc} \right]$$

$$= \pi \left[\frac{(314a) + (315)}{4\ (6)} \right] \left[\begin{array}{l} \text{Look up rotor punching magnetization} \\ \text{curve given in (18) at density (315).} \end{array} \right]$$

(318)	ϕ_{PCL}	FLUX IN THE POLE CENTER AT FULL LOAD

$$\phi_{PCL} = \phi_{gp} + \phi_{\ell s} = (311) + (312a)$$

(319)	B_{PCL}	DENSITY IN THE POLE CENTER AT FULL LOAD

$$B_{PCL} = \frac{\phi_{PCL}}{b_p \ell_{rs}} = \frac{(318)}{(314)\ (305a)}$$

(320)	F_{PCL}	AMPERE TURN DROP IN POLE CENTER AT FULL LOAD

$$F_{PCL} = h_r \left[\text{NI/in. @ } B_{PCL} \right]$$

$$= (303) \left[\begin{array}{l} \text{Look up rotor punching magnetization} \\ \text{curve given in (18) at density (319).} \end{array} \right]$$

(321)	B_{rcL}	THE FLUX DENSITY IN THE ROTOR CORE AT 100% LOAD $$B_{rcL} = \frac{\phi_{PCL}}{2h_{rc}\ell_{rs}} = \frac{(318)}{2(315)(305a)}$$
(322)	F_{rcL}	AMPERE TURNS DROP PER POLE IN THE ROTOR CORE AT 100% LOAD $$F_{rcL} = \frac{\pi(d_s - h_{rc})}{4P}\ NI @ B_{rcL}$$ $$F_{rcL} = \pi\left[\frac{(314a) + (315)}{4(6)}\right]$$ [Look up rotor magnetization curve given in (18) at density (321).]
(330)	h'_{rc}	$$(330) = h'_{rc} = \frac{d_r - 2h_r - d_s}{2} = \frac{(11a) - 2(303) - (314a)}{2}$$
(331)	C_F	RATIO OF FIELD INTERLINKAGE WITH ITS OWN FLUX TO THE MAXIMUM INTERLINKAGE OF A CONCENTRATED FIELD WINDING BASED ON A ROTOR WITH SOLID CENTER SECTION $$C_F = 1 - \alpha + \frac{\alpha}{3K_r} = 1 - (302) + \frac{(302)}{3(308)}$$ BASED ON A ROTOR WITH SLOTTED CENTER SECTION When the center is slotted instead of solid K_r is included in the effective gap and K_r becomes unity in the C_1 equation. $$C_F = 1 - \alpha - \frac{\alpha}{3} = 1 - \frac{2\alpha}{3} = 1 - \frac{2(302)}{3}$$

(332) λ_F

LEAKAGE PERMEANCE OF THE FIELD WINDING

$$\lambda_F = \lambda_{rs} + \lambda_{FE}$$

$$= (312b) + (333)$$

(333) λ_{FE}

LEAKAGE PERMEANCE OF THE ROTOR WINDING END EXTENSION

$$\lambda_{FE} = \frac{6.28}{\ell_r}\left[\frac{\phi_E L_E}{2n}\right] \qquad \frac{6.28}{(305)}\left[\frac{Q_E L_E}{2n}\right]$$

$\dfrac{\phi_E L_E}{2n}$ is taken from the 50% pitch curve of Graph #1

INPUT AUXILIARY DATA SHEET

Auxiliary information taken from the design manuals to be used in conjunction with input sheets for convenience.

A. All dimensions for lengths, widths, and diameters are to be given in inches.

B. Resistivity inputs, Items (141) and (151) are to be given in micro-ohm-inches.

The following items along with an explanation of each are tabulated here for convenience. For complete explanation of each item number, refer to design manuals.

Item No.	Explanation
(9)	Power factor to be given in per unit. For example for 90% P.F., insert .90.
(9a)	Adjustment Factor - For P.F. $<$ .95 insert 1.0 For P.F. $>$ .95 insert 1.05
(10)	Optional Load Point -- Where load data output is required at a point other than those given as standard on the input sheet. Example: For load data output at 155% load, insert 1.55.
(14)	Number of radial ducts in stator.
(15)	Width of radial ducts used in Item (14).
(18)	Magnetization curve of material used to be submitted as defined in Item (18).
(19)	Watts/Lb. to be taken from a core loss curve at the density given in Item (20) (Stator).
(20)	Density in kilolines/in^2. This value must correspond to density used to pick Item (19) usually use 77.4 KL/in^2.
(21)	Type of slot - For open slot Type A, insert 1.0. For partially open slot Type B with constant slot width, insert 2.0. For partially open slot Type C with constant tooth width, insert 3.0. For round slot Type D, insert 4.0. For additional information, refer to figure adjacent to input sheet which shows a picture of each slot.
(22)	For stator slot dimension - for dimensions that do not apply to the slot insert 0.0. Use Table below as guide for input.

Symbol	Item	Slot Type 1	2	3	4
b_o	(22)	0.0	*	*	*
b_1		0.0	0.0	*	0.0
b_2		0.0	0.0	*	0.0
b_3		0.0	0.0	*	0.0
b_s		*	*	$\wp$	*
h_o		0.0	*	*	*
h_1		*	*	*	0.0
h_2		*	0.0	0.0	0.0
h_3		*	*	0.0	0.0
h_s		*	*	*	*
h_t		0.0	*	*	0.0
h_w		0.0	*	*	0.0

* = insert actual value.

$$\wp = b_s = \frac{b_1 + b_3}{2}$$

Item No.	Explanation
(28)	Type of winding - for wye connected winding insert 1.0.
	for delta connected winding insert 0.0.
(29)	Type of coil - for formed wound (rect. wire), insert 1.0.
	for random wound (round wire) insert 0.0.
(30)	Slots spanned - Example - for slot span of 1-10, insert 9.0.
(33)	For round wire insert diameter. For rectangular wire insert wire width.
(34)	Strands per conductor in depth only.
(34a)	Total strands per conductor in depth and width.
(35)	Diameter of coil head forming pin. Insert .25 for stator O.D. < 8 inches:
	Insert .50 for stator O.D. > 8 in.
(37)	Use vertical height of strand for round wire, insert 0.0.
(38)	Distance between centerline of strands in depth.
(39)	Stator strand thickness -- use narrowest dimension of the two dimensions given for a rectangular wire. For round wire insert 0.0.
(40)	Stator slot skew in inches.
(42a)	Phase belt angle - for 60° phase belt, insert 60°.
	for 120° phase belt, insert 120°.
(48)	See explanation of items (71), (72), (73), (74) and (75). Same applies here.
(87)	When no load saturation output data is required at various voltages, insert 1.0.
	When no load saturation information is not required, insert 0.0.
(137)	Damper bar thickness -- use damper bar slot height for rectangular bar. For round bar insert 0.0.
(138)	Number of damper bars per pole.
(140)	Damper bar pitch in inches.
(148)	For round wire insert diameter. For rectangular wire insert wire width.
(149)	For rectangular wire insert wire thickness. For round wire insert 0.0.
(187)	Pole face loss factor. For rotor lamination thickness .028 in. or less, insert 1.17.
	For rotor lamination thickness .029 in. to .063 in. insert 1.75.
	For rotor lamination thickness .064 in. to .125 insert 3.5.
	For solid rotor insert 7.0.
(71) (72) (73) (74) (75)	If the values of these constants are available, insert the actual number. If they are not available, insert 0.0 and the computer will calculate the values and record them on the output.

Insulation

ROTATING COIL LUNDELL

COMPUTER DESIGN - - - - - - - - (INPUT)

MODEL ____________ EWO ________ DESIGN NO(1) ____________

PARAMETERS	(2)	KVA	GENERATOR KVA		FUND/MAX OF FLD FLUX	(71)	C_1	CONSTANTS
	(3)	E	LINE VOLTS		WINDING CONSTANT	(72)	C_w	
	(4)	E_{ph}	PHASE VOLTS		POLE CONSTANT	(73)	C_p	
	(5)	m	PHASES		END EXTENSION ONE TURN	(48)	L_E	
	(5a)	f	FREQUENCY		DEMAGNETIZATION FACTOR	(74)	C_m	
	(6)	p	POLES		CROSS MAGNETIZING FACTOR	(75)	C_q	
	(7)	RPM	RPM		POLE EMBRACE	(77)	α	
	(8)	I_{ph}	PHASE CURRENT		WIDTH OF POLE (NARROW END)	(76)	b_{p1}	POLE AND ROTOR
	(9)	PF	POWER FACTOR		WIDTH OF POLE (WIDE END)	(76)	b_{p2}	
	(9a)	K_c	ADJ. FACTOR		POLE THICKNESS (NARROW END)	(76)	t_{p1}	
	(10)		OPTIONAL LOAD POINT		POLE THICKNESS (WIDE END)	(76)	t_{p2}	
STATOR STACK	(11)	d	STATOR I.D.		POLE LENGTH	(76)	ℓ_p	
	(12)	D	STATOR O.D.		ROTOR DIAMETER	(11a)	d_r	
	(13)	ℓ	GROSS CORE LENGTH		WEIGHT OF ROTOR IRON	(157)	(–)	
	(14)	n_v	NO. OF DUCTS		POLE FACE LOSS FACTOR	(187)	(K_1)	
	(15)	b_v	WIDTH OF DUCT		FLUX PLATE THICKNESS	(78)	(t_{fp})	
	(16)	K_i	STACKING FACTOR (STATOR)		FLUX PLATE DIAMETER	(78)	(d_{fp})	
	(19)	k	WATTS/LB.		SHAFT O.D.(FLUX CARRYING PORT.)	(78)	(d_s)	SHAFT
	(20)	B	DENSITY		SHAFT LENGTH(FLUX CARRYING PORT)	(78)	(ℓ_{SH})	
STATOR SLOT	(21)		TYPE OF SLOT		PERM OF LEAKAGE PATH 1	(80)	P_1	PERMEANCE
	(22)	b_o	SLOT OPENING		PERM OF LEAKAGE PATH 2	(81)	P_2	
	(22)	b_1	SLOT WIDTH TOP		PERM OF LEAKAGE PATH 3	(82)	P_3	
	(22)	b_2			PERM OF LEAKAGE PATH 4	(83)	P_4	
	(22)	b_3			PERM OF LEAKAGE PATH 5	(84)	P_5	
	(22)	b_s	SLOT WIDTH		PERM OF LEAKAGE PATH 7	(86)	P_7	
	(22)	h_o			OUTSIDE DIAMETER OF FLD COIL	(78)	d_{oc}	FIELD
	(22)	h_1			LENGTH OF FIELD COIL	(76)	ℓ_{oc}	
	(22)	h_2			NO. OF FIELD TURNS/COIL	(146)	N_f	
	(22)	h_3			MEAN LENGTH OF FLD. TURN	(147)	ℓ_f	
	(22)	h_s	SLOT DEPTH		FLD. COND. DIA. OR WIDTH	(148)		
	(22)	h_t			FLD. COND. THICKNESS	(149)		
	(22)	h_w			FLD. TEMP IN °C	(150)	X_f °C	
	(23)	Q	NO. OF SLOTS		RESISTIVITY OF FIELD COND @ 20°	(151)	ρ_f	
STATOR WINDING	(28)		TYPE OF WDG.		NO LOAD SAT.	(87)		
	(29)		TYPE OF COIL		FRICTION & WINDAGE	(183)	(F&W)	
	(30)	n_s	CONDUCTORS/SLOT		SPECIAL PERMEANCE	64a	λ_z	
	(31)	y	SLOTS SPANNED		STATOR LAM MATERIAL	(18)		MATERIAL
	(32)	c	PARALLEL CIRCUITS		POLE MATERIAL	(18)		
	(33)		STRAND DIA. OR WIDTH		SHAFT MATERIAL	(18)		
	(34)	N_{st}	STRANDS/CONDUCTOR IN DEPTH					
	(34a)	N'_{st}	STRANDS/CONDUCTOR					
	(39)		STATOR STRAND T'KNS.					
	(35)	d_b	DIA. OF PIN					
	(36)	ℓ_{e2}	COIL EXT. STR. PORT					
	(37)	h_{st}	UNINS. STRD. HT.					
	(38)	h'_{st}	DIST. BTWN. C_L OF STD.					
	(42a)		PHASE BELT ANGLE					
	(40)	τ_{sk}	STATOR SLOT SKEW					
	(50)	X °C	STATOR TEMP °C					
	(51)	ρ_s	RES'TVY STA. COND. @ 20°C					
GAP	(59)	g	MAIN GAP					

STATOR SLOT	POLE
DAMPER SLOT	REMARKS

J-01 DESIGNER ____________ DATE ____________

ROTATING COIL LUNDELL

SUMMARY OF DESIGN CALCULATIONS - - - - - - - (OUTPUT)

MODEL NO. ______________________ EWO ____________ DESIGN NO. ______________________

STATOR	(17)	(ℓ_s)	SOLID CORE LENGTH			CARTER COEFFICIENT	(67)	(K_s)	CONSTANTS
	(24)	(h_c)	DEPTH BELOW SLOT			EFFECTIVE AIR GAP	(69)	(g_e)	
	(26)	(τ_s)	SLOT PITCH			FUND/MAX OF FLD FLUX	(71)	(C_1)	
	(27)	(τ_s 1/3)	SLOT PITCH 1/3 DIST. UP			WINDING CONST.	(72)	(C_w)	
	(42)	(K_{sk})	SKEW FACTOR			POLE CONST.	(73)	(C_p)	
	(43)	(K_d)	DIST. FACTOR			END. EXT. ONE TURN	(48)	(L_E)	
	(44)	(K_p)	PITCH FACTOR			DEMAGNETIZING FACTOR	(74)	(C_M)	
	(45)	(η_e)	EFF. CONDUCTORS			CROSS MAGNETIZING FACTOR	(75)	(C_q)	
	(46)	(a_c)	COND. AREA			AMP COND/IN	(128)	(A)	REACTANCE
	(47)	(S_s)	CURRENT DENSITY (STA.)			REACTANCE FACTOR	(129)	(X)	
	(49)	(ℓ_t)	1/2 MEAN TURN LENGTH			LEAKAGE REACTANCE	(130)	(X_ℓ)	
	(53)	(R_{ph})	COLD STA. RES. @ 20° C			REACTANCES OF	(131)	(X_{ad})	
	(54)	(R_{ph})	HOT STA. RES. @ X°C			ARMATURE REACTION	(132)	(X_{aq})	
	(55)	(EF_{top})	EDDY FACTOR TOP			SYN REACT DIRECT AXIS	(133)	(X_d)	
	(56)	(EF_{bot})	EDDY FACTOR BOT			SYN REACT QUAD AXIS	(134)	(X_q)	
	(62)	(λ_i)	STATOR COND. PERM.			FIELD LEAKAGE REACT	(160)	(X'_f)	
	(64)	(λ_e)	END PERM.			FIELD SELF INDUCTANCE	(161)	(L_f)	
	(65)	(—)	WT. OF STA COPPER			UNSAT. TRANS. REACT	(166)	(X'_{du})	
	(66)	(—)	WT. OF STA. IRON			SAT. TRANS. REACT	(167)	(X'_d)	
	(41)	(τ_p)	POLE PITCH			NEG SEQUENCE REACT	(170)	(X_2)	
	(157)	(—)	WT. OF ROTOR IRON			ZERO SEQUENCE REACT	(172)	(X_0)	
	(145)	(V_r)	PERIPHERAL SPEED			OPEN CIR. TIME CONST.	(176)	(T_{do})	TIME CONST.
FIELD	(153)	(a_{cf})	FLD COND. AREA			ARM TIME CONST.	(177)	(T_a)	
	(154)	(R_f)	COLD FLD RES. @ 20° C			TRANS. TOME CONST.	(178)	(T'_d)	
	(155)	(R_f)	HOT FLD RES. @ X°C			SUB TRAN TIME CONST.	(179)	(T''_d)	
	(156)	(—)	WT. OF FLD COPPER			TOTAL FLUX	(88)	(ϕ_T)	MAGNETIZATION
PERMEANCE	(80)	(P_1)	PERM OF LEAKAGE PATH 1			FLUX PER POLE	(92)	(ϕ_p)	
	(81)	(P_2)	PERM OF LEAKAGE PATH 2			GAP DENSITY (MAIN)	(95)	(B_g)	
	(82)	(P_3)	PERM OF LEAKAGE PATH 3			TOOTH DENSITY	(91)	(B_t)	
	(83)	(P_4)	PERM OF LEAKAGE PATH 4			CORE DENSITY	(94)	(B_c)	
	(84)	(P_5)	PERM OF LEAKAGE PATH 5			TOOTH AMPERE TURNS	(97)	(F_t)	
	(85)	(P_7)	PERM OF LEAKAGE PATH 7			CORE AMPERE TURNS	(98)	(F_c)	
	(180)	(F_{SC})	SHORT CIR NI			GAP AMPERE TURNS (MAIN)	(96)	(F_g)	
	(181)	(S_{CR})	SHORT AIR RATIO						

PERCENT LOAD	0		100	150	200	OPTIONA
(ϕ_ℓ) (100a) LEAKAGE FLUX		(ϕ_{gg}) (197a)				
(ϕPT) (102a) TOTAL FLUX/POLE		(ϕP_{fl}) (213a)				
(B_p) (103a) POLE DENSITY		(B_{pl}) (213b)				
(B_{sh}) (113) SHAFT DENSITY		(B_{shl}) (232)				
(F_{nl}) (127) TOTAL NI		(F_{fl}) (236)				
(I_{fnl}) (127a) FIELD AMPERES		(I_{fH}) (237)				
(S_f) (127c) CUR. DEN. FLD.		(S_{FL}) (239)				
(E_{fnl}) (127b) FIELD VOLTS		(E_{fl}) (238)				
(W_c) (185) STA CORE LOSS		(W_c) (185)				
(W_{tnl}) (184) STA TOOTH LOSS		(W_{tfl}) (242)				
($I^2 R_a$) (194) STATOR CU LOSS		($I^2 R_L$) (245)				
(—) (195) EDDY LOSS		(—) (246)				
(W_{pnl}) (186) POLE FACE LOSS		(W_{pfl}) (243)				
($I^2 R_f$) (182) FIELD COIL LOSS		($I^2 R_{fl}$) (241)				
(F&W) (183) F&W LOSS		(F&W) (183)				
(—) (196) TOTAL LOSSES		(—) (247)				
(—) (—) PERCENT EFF.		(—) (251)				

REV. A

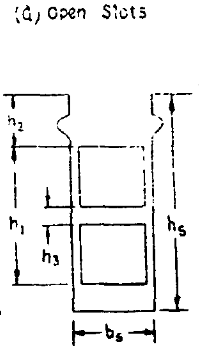
ROTATING COIL LUNDELL

NO LOAD SATURATION OUTPUT SHEET

ITEMS / % VOLTS	(3) (E) VOLTS	(91) B_t STA. TOOTH DENSITY	(97) F_t STATOR TOOTH N.I.	(94) B_c STA. CORE DENSITY	(98) F_c STA. CORE N.I.	(96) F_g GAP N.I.
	(100a) Φ_ℓ LEAKAGE FLUX	(102a) ϕ_{pt} TOTAL FLUX/POLE	(103a) B_p POLE DENSITY	(104a) F_p POLE N.I.	(113) B_{sh} SHAFT DENSITY	(127) F_{nl} TOTAL N.I.
80%						
90%						
100%						
110%						
120%						
130%						
140%						
150%						
160%						

REV. A

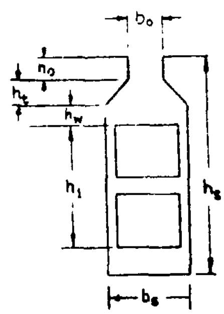
(a) Open Slots



TYPE 1

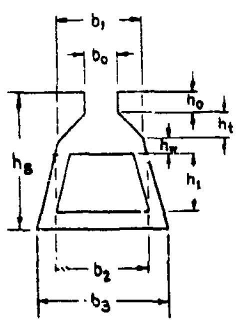
(Type 5 is an open slot with 1 conductor per slot)

(b) Constant Slot Width



TYPE 2

(c) Constant Tooth Width

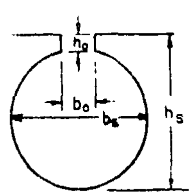


TYPE 3

b_s for type 3 is

$$b_s = \left(\frac{b_1 + b_3}{2}\right)$$

(d) Round Slots



TYPE 4

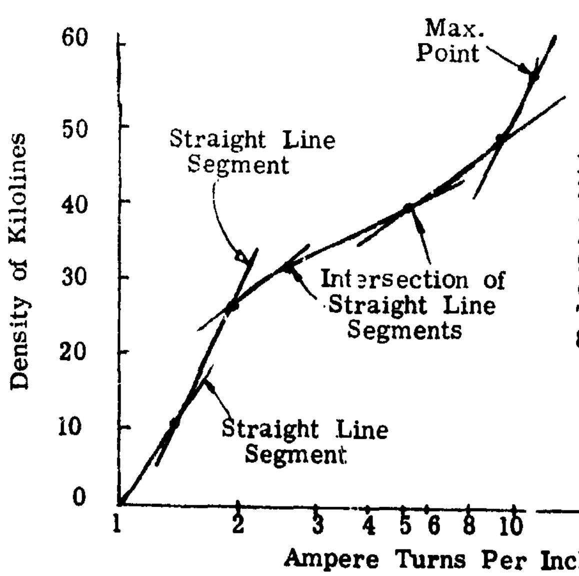
INSIDE-COIL ROTATING-COIL LUNDELL GENERATOR

(1)	--	DESIGN NUMBER
(2)	KVA	GENERATOR KVA
(3)	E	LINE VOLTS
(4)	E_{PH}	PHASE VOLTS
(5)	m	PHASES
(5a)	f	FREQUENCY
(6)	P	POLES
(7)	RPM	SPEED
(8)	I_{PH}	PHASE CURRENT
(9)	P. F.	POWER FACTOR
(9a)	K_c	ADJUSTMENT FACTOR
(10)	--	LOAD POINTS
(11)	d	STATOR PUNCHING I.D.
(11a)	d_r	ROTOR O.D.
(12)	D	PUNCHING O.D.
(13)	ℓ	GROSS STATOR CORE LENGTH
(14)	n_v	RADIAL DUCTS
(15)	b_v	RADIAL DUCT WIDTH
(16)	K_i	STACKING FACTOR
(17)	ℓ_s	SOLID CORE LENGTH

(18) **MATERIAL** - This input is used in selecting the proper magnetization curves for stator, yoke, pole, and shaft; when different materials are used. Separate spaces are provided on the input sheet for each section mentioned above. Where curves are available on card decks, used the proper identifying code. Where card decks are not available submit data in the following manner:

The magnetization curve must be available on semi-log paper. Typical curves are shown in this manual on Curves F-15 & 16. Draw straight line segments through the curve starting with zero density. Record the coordinates of the points where the straight line segments intersect. Submit these coordinates as input data for the magnetization curve. The maximum density point must be submitted first.

Refer to Figure below for complete sample



Sample Input Data

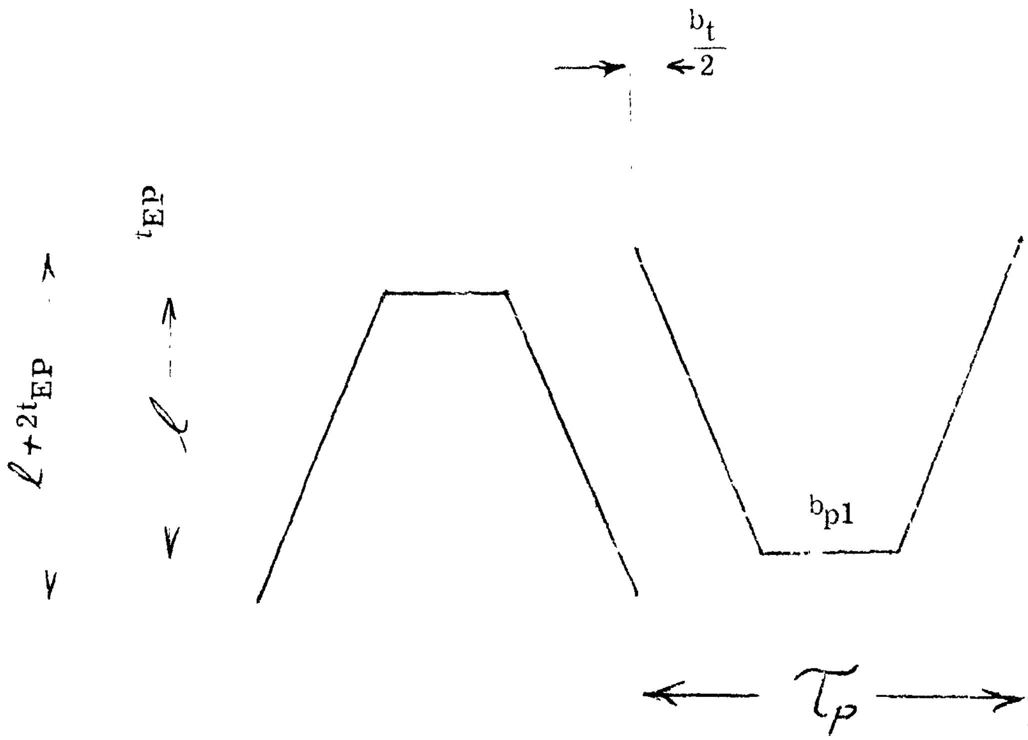
	Density	NI
1)	55	—
2)	0	0
3)	10	1.5
4)	27	1.9
5)	32	2.5
6)	40	4.9
7)	48	9.0
8)	55	12.0

(19)	k	WATTS LB
(20)	B	DENSITY
(21)		TYPE OF STATOR SLOT
(22)		ALL SLOT DIMENSIONS
(23)	Q	STATOR SLOTS
(24)	h_c	DEPTH BELOW SLOTS
(25)	q	SLOTS PER POLE PER PHASE
(26)	τ_s	STATOR SLOT PITCH
(27)	τ_s 1/3	STATOR SLOT PITCH
(28)	--	TYPE OF WINDING
(29)	--	TYPE OF COIL
(30)	n_s	CONDUCTORS PER SLOT
(31)	Y	THROW
(31a)		PER UNIT OF POLE PITCH SPANNED
(32)	C	PARALLEL PATHS
(33)	--	STRAND DIA. OR WIDTH
(34)	N_{ST}	NUMBER OF STRANDS PER CONDUCTOR IN DEPTH
(34a)	N'_{ST}	NUMBER OF STRANDS PER CONDUCTOR
(35)	d_b	DIAMETER OF BENDER PIN
(36)	ℓ_{e2}	COIL EXTENSION BEYOND CORE
(37)	h_{ST}	HEIGHT OF UNINSULATED STRAND
(38)	h'_{ST}	DISTANCE BETWEEN CENTERLINES OF STRANDS IN DEPTH

(39)	--	STATOR COIL STRAND THICKNESS
(40)	τ_{SK}	SKEW
(41)	τ_P	POLE PITCH
(42)	K_{SK}	SKEW FACTOR
(42a)		PHASE BELT ANGLE
(43)	K_d	DISTRIBUTION FACTOR
(44)	K_p	PITCH FACTOR
(45)	n_e	TOTAL EFFECTIVE CONDUCTORS
(46)	a_c	CONDUCTOR AREA OF STATOR WINDING
(47)	S_S	CURRENT DENSITY
(48)	L_E	END EXTENSION LENGTH
(49)	ℓ_t	1/2 MEAN TURN
(50)	$X_s\ ^oC$	STATOR TEMP ^oC
(51)	ρ_s	RESISTIVITY OF STATOR WINDING
(52)	$\rho_{s\,(hot)}$	RESISTIVITY OF STATOR WINDING
(53)	R_{SPH} (cold)	STATOR RESISTANCE/PHASE
(54)	R_{SPH} (hot)	STATOR RESISTANCE/PHASE
(55)	EF (top)	EDDY FACTOR TOP
(56)	EF (bot)	EDDY FACTOR BOTTOM

(57)	b_{tm}	STATOR TOOTH WIDTH
(57a)	b_t 1/3	STATOR TOOTH WIDTH
(58)	b_t	TOOTH WIDTH AT STATOR I.D. IN INCHES
(59)	g	MAIN AIR GAP IN INCHES
(60)	C_X	REDUCTION FACTOR
(61)	K_X	FACTOR TO ACCOUNT FOR DIFFERENCE in phase current in coil sides in same slot.
(62)	λ_i	CONDUCTOR PERMEANCE
(63)	K_E	LEAKAGE REACTIVE FACTOR
(64)	λ_E	END WINDING PERMEANCE
(64a)	λ_z	SPECIAL LEAKAGE PERMEANCE - For machines having a section of the pole that is approximately a full pole pitch wide, an additional leakage permeance must be added to the slot and end-turn leakage permeances. This permeance is that of the leakage path from one pole into a tooth top and from tooth top back into the adjacent pole. The leakage is similar to Zig Zag leakage and by increasing the stator leakage reactance, can reduce the output of the generator significantly. This same leakage can be used to

purposely limit the output of the generator and make it current limited. The presence of this additional leakage can be good or bad depending upon what is wanted from the generator. The important thing is for the designer to be aware that it is there.



$$\lambda_z = (C_x)\,\frac{20}{(m)(q)}\,\frac{\text{area of pole over tooth when tooth is on center line between poles}}{2\,\ell\,g_e}$$

$$\lambda_z = (C_x)\,\frac{20}{(m)(q)}\,\frac{b_t\,(\tau_p - b_{p1})\,(\ell + 2\,t_{EP})\,\frac{(\tau_p - b_{p1})}{\tau_p}}{2\,\ell\,g_e}$$

This calculation is not programmed and the value λ_z must be given as an input on the input sheet. If the pole embrace at the base of the pole is appreciably less than one, the input for λ_z is zero. If the pole embrace is near unity, the designer may be forced to estimate the value λ_z instead of using the calculation given above.

(65)	--	WEIGHT OF COPPER
(66)	--	WEIGHT OF STATOR IRON
(67)	K_s	CARTER COEFFICIENT
(68)	--	MAIN AIR GAP AREA
(69)	g_e	EFFECTIVE AIR GAP
(70c)	λ_a	AIR GAP PERMEANCE
(71)	C_1	THE RATIO OF MAXIMUM FUNDAMENTAL of the field form to the actual maximum of the field form

(72)	C_W	<u>WINDING CONSTANT</u>
(73)	C_P	<u>POLE CONSTANT</u>
(74)	C_M	<u>DEMAGNETIZING FACTOR</u>
(75)	C_q	<u>CROSS MAGNETIZING FACTOR</u>
(76)	--	<u>POLE DIMENSIONS</u> -

b_{p2} = width of pole at edge of stator stack

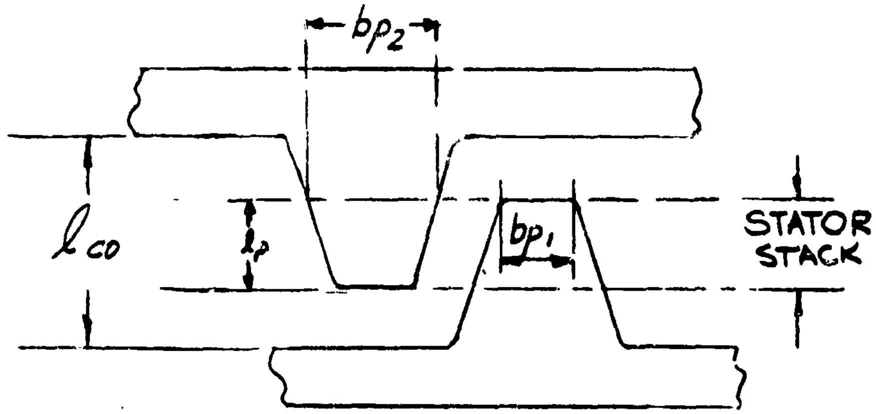
b_{p1} = width of pole at end

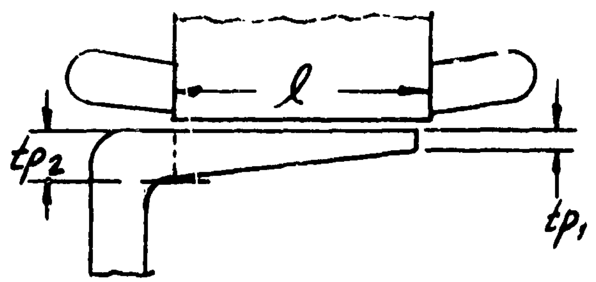
t_{p2} = thickness of pole at edge of stator stack

t_{p1} = thickness of pole at end

ℓ_{co} = length of coil

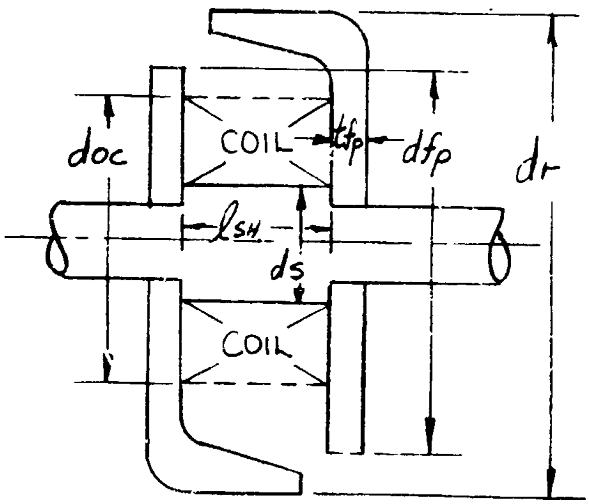
ℓ_p = length of pole





(77)	α	**POLE EMBRACE** - $$= \frac{(b_{p1}) + (b_{p2})}{2\tau_p} = \frac{(76) + (76)}{2(41)}$$
(77a)	--	Items immediately following deal with the calculation of rotor and stator leakage permeances. Illustrations are included to help identify the permeance areas and to locate the flux leakage paths. The computer program will handle the calculation of permeances P_1, P_2, P_3 and P_4 either of two ways: 1. P_1 through P_4 can be calculated by the computer. For this case, insert 0.0 on the input sheet for P_1 through P_4. 2. P_1 through P_4 can be calculated by the designer. For this case, insert the actual calculated value on the input sheet for P_1 through P_4. Permeance P_5 and P_7 must be calculated by the designer and the calculated value must be inserted on the input sheet. The computer will not calculate these two permeance values because of the various possible field coil locations.

(78) -- ROTOR, COIL AND SHAFT DIMENSIONS - These dimensions are inputs and are required in the calculations that follow:



ℓ_{sh} = length of shaft (flux carrying portion)

d_{fp} = diameter of flux plate

d_r = outside dia. of rotor (also identified in item (11a)

d_{oc} = outside diameter of coil

d_s = outside dia. of shaft (flux carrying portion)

t_{fp} = thickness of flux plate

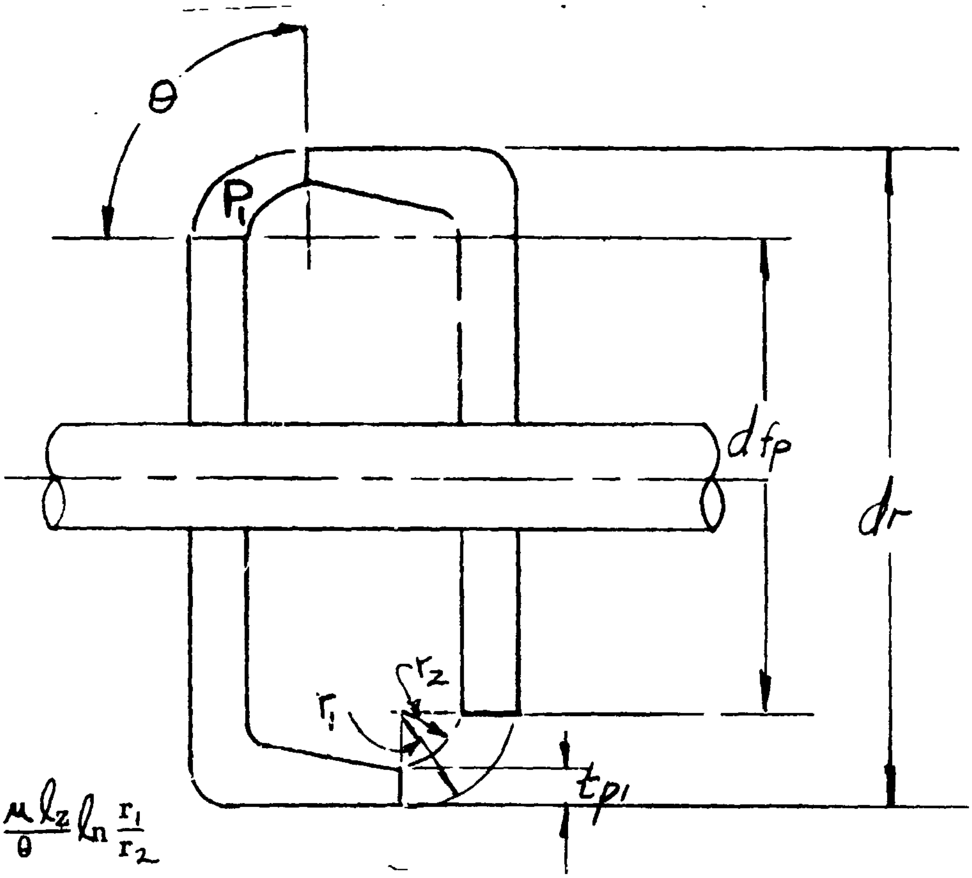
(79) a_p POLE AREA - The effective cross-sectional area of the pole.

$$a_p = (b_{p2})(t_{p2}) = (76)(76)$$

(80) P_1 POLE HEAD END LEAKAGE - This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure J-4 for location.

$$P_1 = \frac{6.28(b_p l)}{\pi} \ell n \frac{r_1}{r_2} = \frac{6.28(76)}{\pi} \ell n \frac{(80b)}{(80a)}$$

P_1 POLE HEAD LEAKAGE



$$P = \frac{\mu l_z}{\theta} \ln \frac{r_1}{r_2}$$

$$r_2 = \frac{d_r - d_{fp}}{2} \qquad r_1 = r_2 + t_{p1}$$

$$P_1 = 2\frac{(3.19)\, b_{p1}}{\pi} \ln \frac{r_1}{r_2}$$

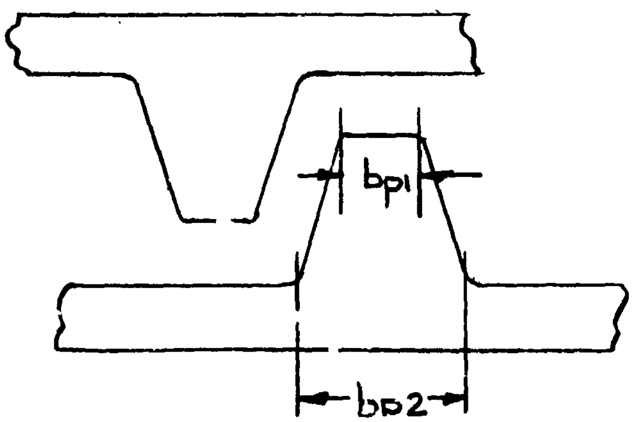


Fig. J-4

(80a) r_2

$$r_2 = \frac{(d_r) - (d_{fp})}{2} = \frac{(11a) - (78)}{2}$$

(80b) r_1

$$r_1 = (r_2) + (t_{p1}) = (80a) + (76)$$

(81) P_2

POLE HEAD SIDE LEAKAGE - This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure J-5 for location.

$$P_2 = \frac{3.19\left\{(\ell_p)\left[\frac{(t_{p2})+(t_{p1})}{2}\right]\right\}}{\ell_2} = \frac{3.19\left\{(76)\left[\frac{(76)+(76)}{2}\right]\right\}}{(81a)}$$

(81a) ℓ_2

LENGTH OF PERMEANCE PATH 2

$$\ell_2 = \tau_p - \left[\frac{(b_{p1}) + (b_{p2})}{2}\right] = (41) - \left[\frac{(76) + (76)}{2}\right]$$

(82) P_3

POLE BODY END LEAKAGE - This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure J-6 for location.

$$P_3 = \frac{6.28\left\{\frac{3(b_{p1})+(b_{p2})}{4}\right\}}{\pi} \ell n \frac{(r_3)}{(r_4)} = \frac{6.28\left\{\frac{3(76)+(76)}{4}\right\}}{\pi} \ell n \frac{(82a)}{(82b)}$$

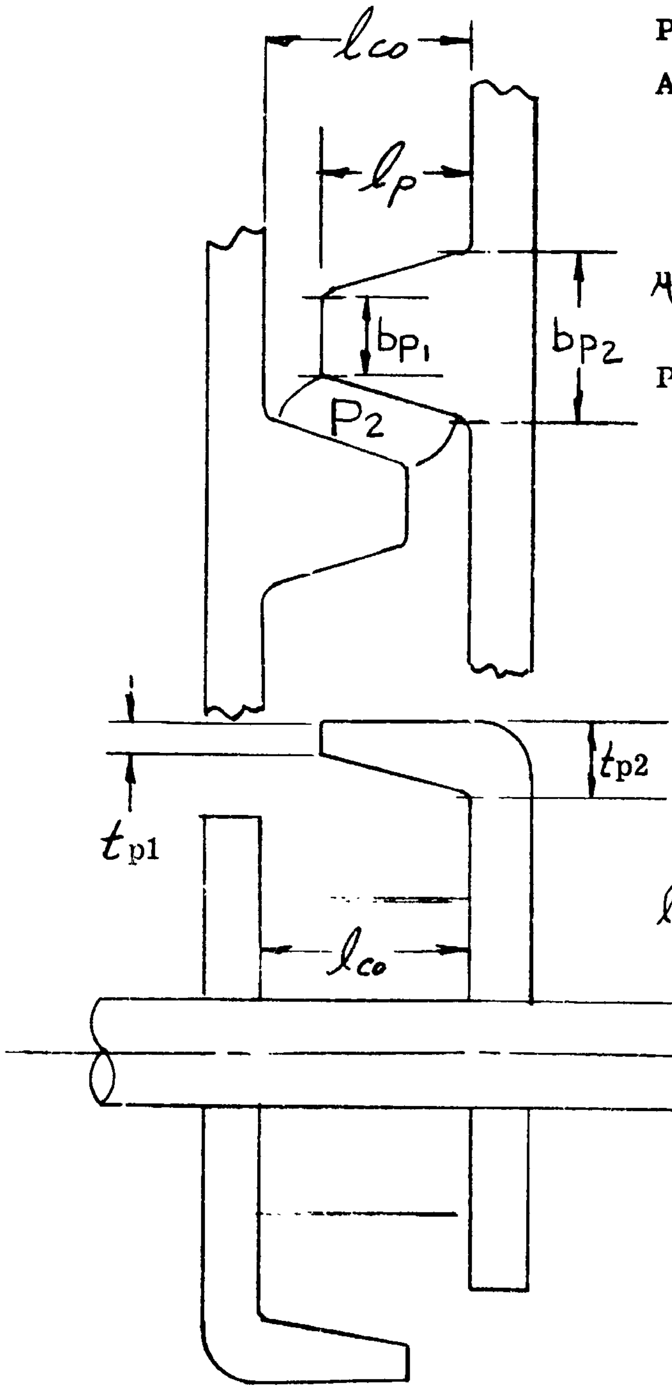
(82a) --

$$r_3 = (r_4) + \frac{(\ell_p)}{2} = (80b) + \frac{(76)}{2}$$

(82b) --

$$r_4 = (r_1) = (80b)$$

P_2 POLE HEAD SIDE LEAKAGE



$$P_2 = \frac{\mu A}{\ell}$$

$$A = \ell_p \frac{t_2 + t_1}{2}$$

$$\ell = \tau_p - \left[\frac{(b_{p1} + b_{p2})}{2}\right]$$

$$\mu = 3.19$$

$$P_2 = \frac{3.19 \left[\ell_p \left\{\frac{(t_{p2}) + (t_{p1})}{2}\right\}\right]}{\tau_p - \left[\frac{b_{p1} + b_{p2}}{2}\right]}$$

ℓ_{co} = length of coil

Fig. J-5

P_3 POLE BODY END LEAKAGE

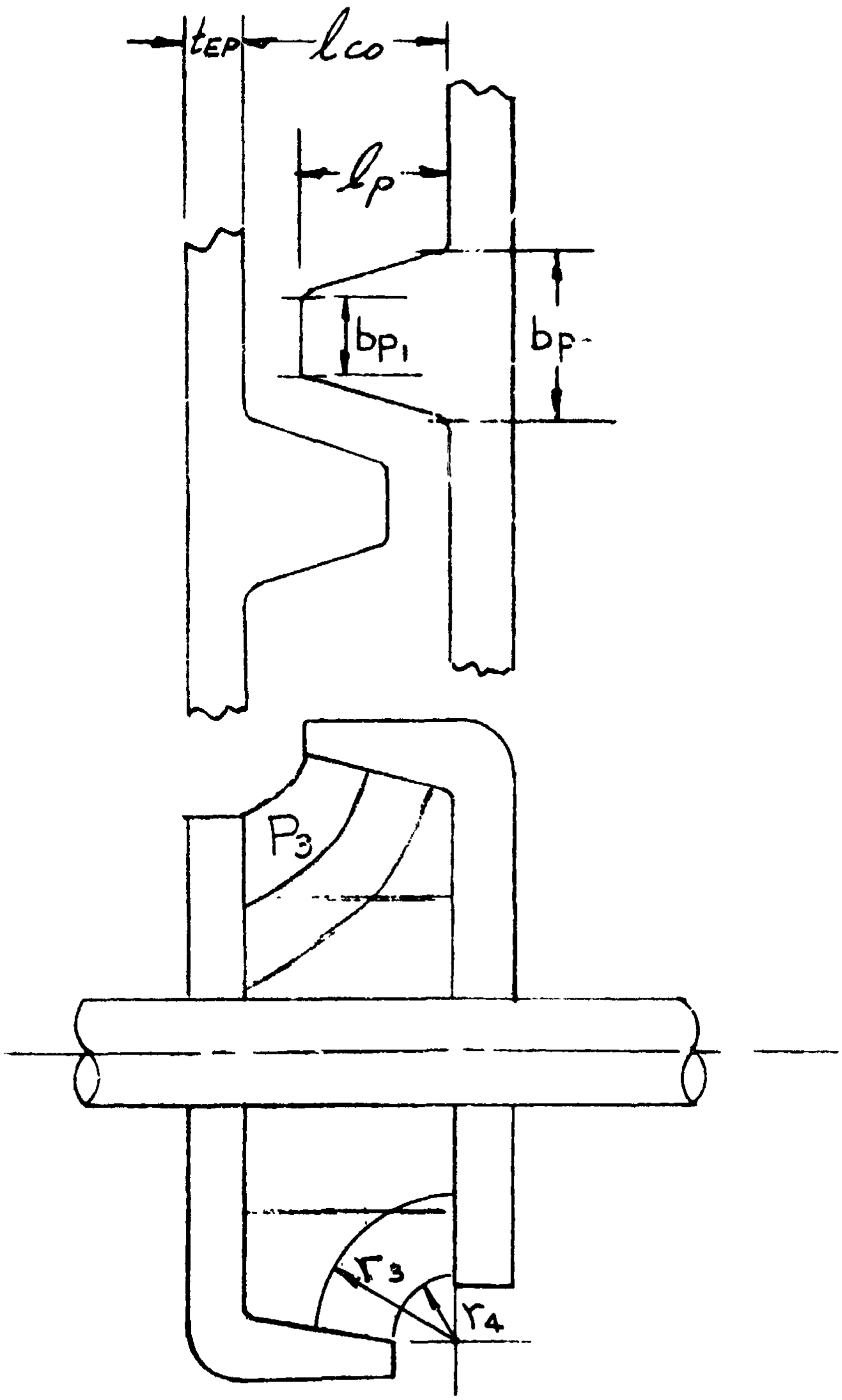


Fig. J-6

(83) P_4 POLE BODY SIDE LEAKAGE - This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure J-7, J-8 for location.

When (6) > 4

$$P_4 = \frac{3.19(\ell_p)}{\pi} \ln \left[1 + \frac{(b_{p1}) + (b_{p2})}{2\,(Z)} \right]$$

$$= \frac{3.19(76)}{\pi} \ln \left[1 + \frac{(76) + (76)}{2\,(83)} \right]$$

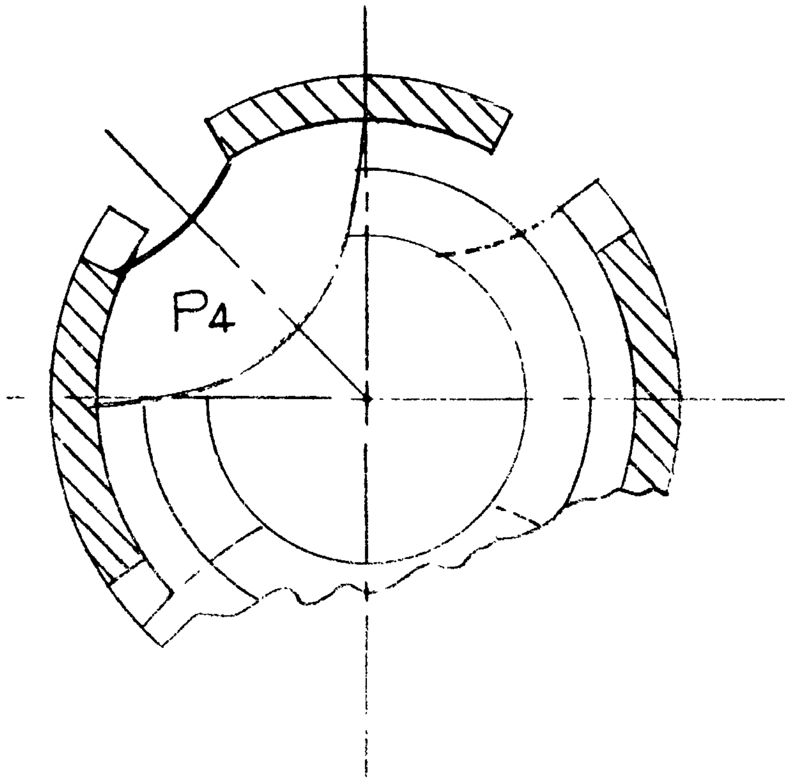
Where $(Z) = \tau_p - \left[\frac{(b_{p1}) + (b_{p2})}{2} \right] = (41) - \left[\frac{(76) + (76)}{2} \right]$

When (6) < 4

$$P_4 = \frac{3.19(\ell_p)}{\pi} \frac{3}{2} \ln \left[1 + \frac{(b_{p1}) + (b_{p2})}{2\,(Z)} \right]$$

$$= \frac{3.19(76)}{\pi} \frac{3}{2} \ln \left[1 + \frac{(76) + (76)}{2\,(83)} \right]$$

(84) P_5 FIELD COIL LEAKAGE PERMEANCE, ROTOR - This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure J-9 for location.



P_4 IN A FOUR-POLE MACHINE

Fig. J-7

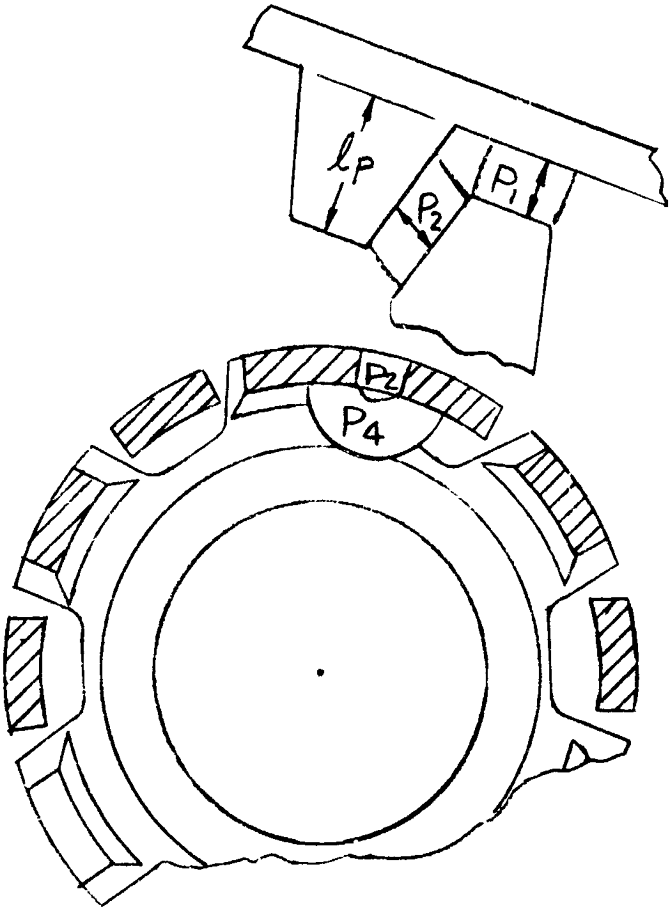


Fig. J-8

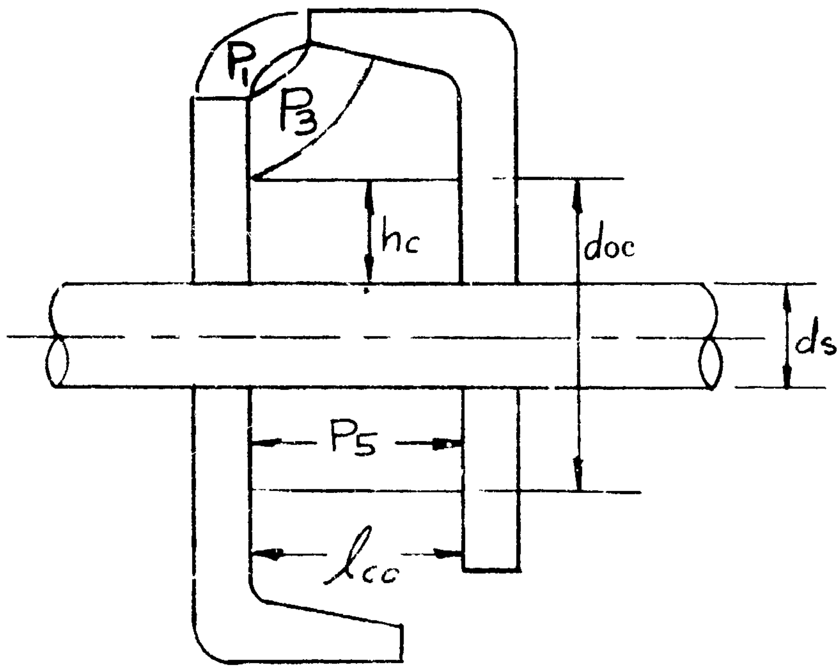


Fig. J-9

$$P_5 = \frac{3.19\pi}{(\ell_{co})}\left[\frac{(d_{\alpha})^2}{4} - \frac{(d_s)^2}{4}\right]\frac{2}{3}$$

$$= \frac{3.19\pi}{(76)}\left[\frac{(78)^2}{4} - \frac{(78)^2}{4}\right]\frac{2}{3}$$

(86) | P_7 | STATOR TO COIL YOKE LEAKAGE - This input can be eithe 0.0 or the actual value if available. Refer to Item (77a) for exp anation. See Figure J-10 for location.

$$P_7 = \frac{2.5(D + d_{fp})(D-d)}{D-d_{fp}}$$

$$= \frac{2.5\left[(12) + (78)\right]\left[(12)-(11)\right]}{(12)-(78)}$$

(87) | | Equations immediately following, deal with the saturation at no-load. When no-load saturation data is desired for different voltages, insert 1. on the input sheet for "no-load saturation". The computer will then calculate no-load saturation points at 80, 90, 100, 110, 120, 130, 140, 150, and 160% of rated volts. If only the saturation data at 100% load is needed, insert 0. on the input sheet.

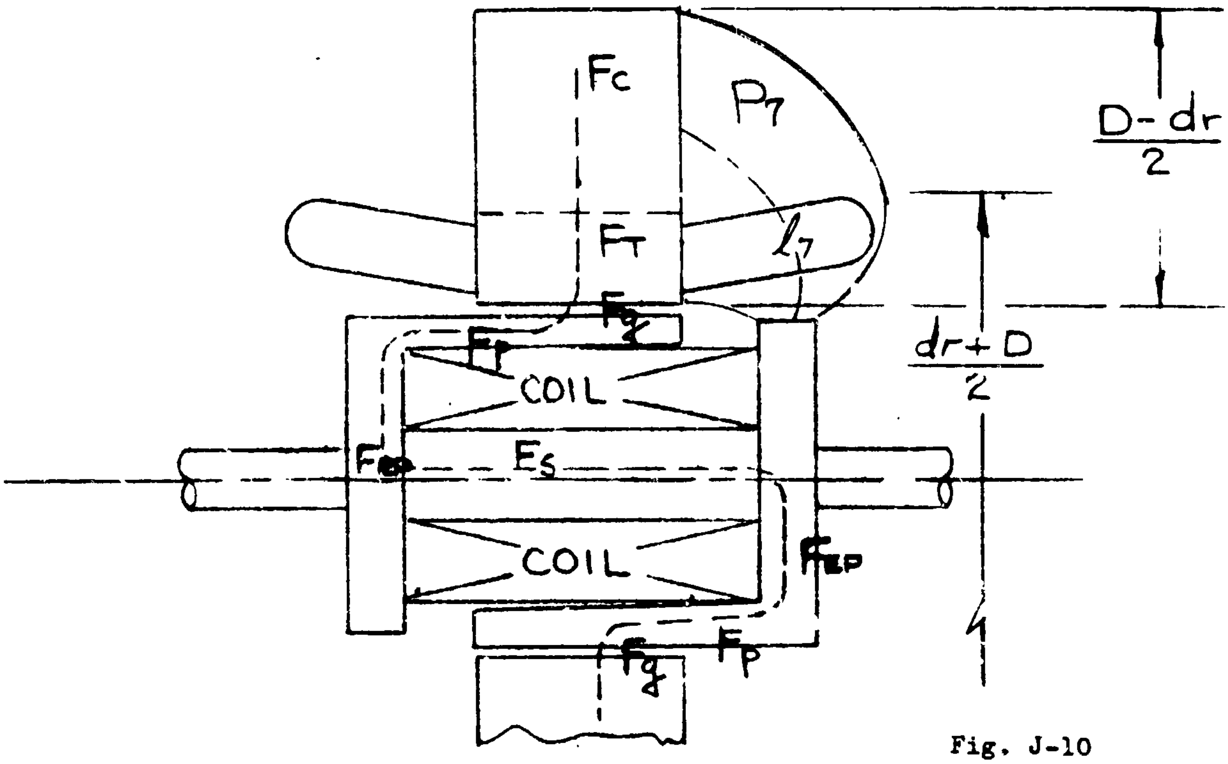


Fig. J-10

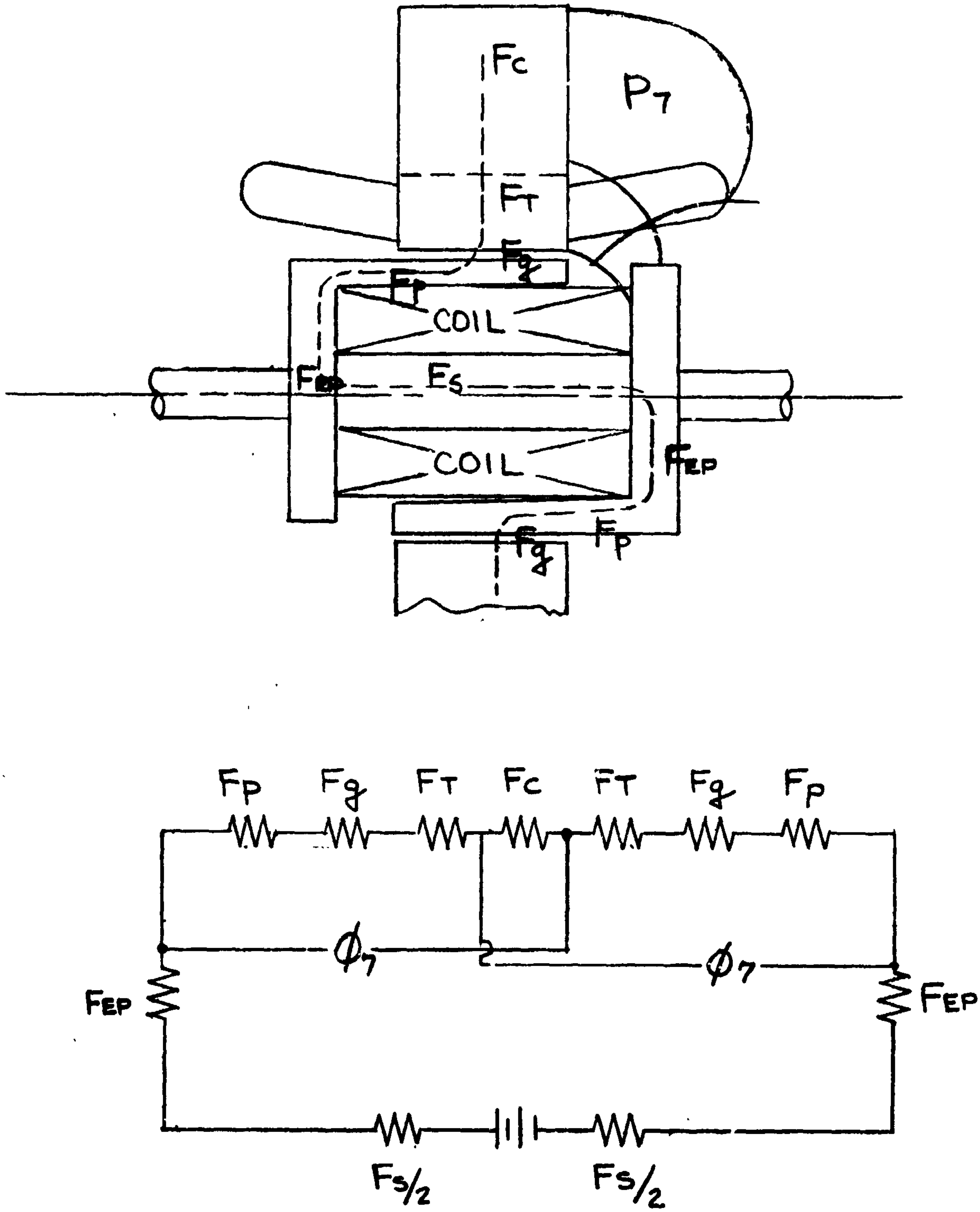

Fc
P7
FT
Fg
Fp
COIL
FEP
Fs
COIL
FEP
Fg
Fp
Fp Fg FT Fc FT Fg Fp
φ7
φ7
FEP
FEP
Fs/2
Fs/2

Fig. J-11

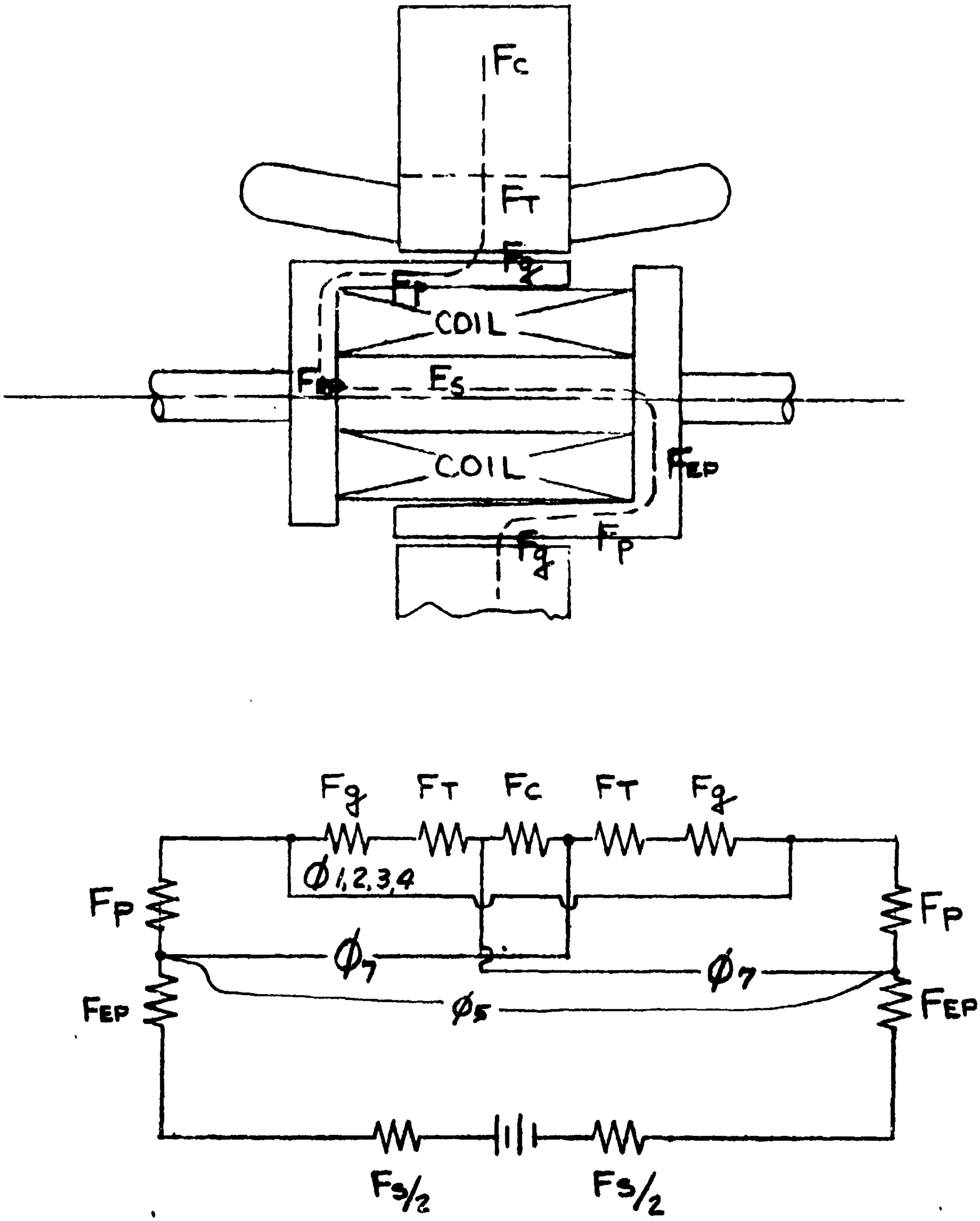

Fc
FT
Fg
Fp
COIL
FEP
Es
COIL
FEP
Fg
Fp
Fg
FT
Fc
FT
Fg
Ø1,2,3,4
Fp
Fp
Ø7
Ø7
FEP
Ø5
FEP
Fs/2
Fs/2

Fig. J-12

(88)	ϕ_T	TOTAL FLUX in Kilolines
(91)	B_t	TOOTH DENSITY in Kilolines/in^2
(92)	ϕ_P	FLUX PER POLE in Kilolines
(94)	B_c	CORE DENSITY in Kilolines/in^2
(95)	B_g	GAP DENSITY in Kilolines/in^2
(96)	F_g	AIR GAP AMPERE TURNS
(97)	F_T	STATOR TOOTH AMPERE TURNS
(98)	F_c	STATOR CORE AMPERE TURNS
(98a)	F_s	STATOR AMPERE TURNS, total
(99)	ϕ_7	LEAKAGE FLUX FROM THE STATOR TO THE FLUX PLATE AT THE END OF THE ROTOR - The same flux leaks from the rotor to the stator on one side & leaks out from the stator to the rotor on the other side. This flux does not pass through the air gap but does pass through the rotor shaft and flux plates.

$$\phi_7 = (P_7)\left[(F_P) + (F_g) + (F_T) + (F_c)\right] \times 10^{-3}$$

$$= (86)\left[(104a) + (96) + (97) + (98)\right] \times 10^{-3}$$

(100a) ϕ_ℓ **LEAKAGE FLUX** - at no load

$$\phi_\ell = (P_e)\left[2(F_g) + 2F_T + F_c\right] \times 10^{-3}$$

$$= (160a)\left[2(96) + 2(97) + (98)\right] \times 10^{-3}$$

(102a) ϕ_{PT} **TOTAL FLUX PER POLE** - at no load

$$\phi_{PT} = \phi_P + \frac{2(\phi_\ell)}{(P)} \quad (92) + \frac{2(100a)}{(6)}$$

(103a) B_P **POLE DENSITY** - The apparent flux density at the base of the pole.

$$B_P = \frac{(\phi_{PT})}{(a_P)} = \frac{(102a)}{(79)}$$

(104a) F_P **POLE AMPERE TURNS** - at no load. The ampere turns per pole required to force the flux through the pole and flux plate at no load rated voltage. In general the flux plate density is kept fairly low and its ampere turns can be neglected. The no load pole ampere turns per pole are calculated as the product of (ℓ_P) times the NI per inch at the density (B_P). Use magnetization curve submitted per Item (18) for rotor.

$$F_P = (\ell_P)\left[\text{NI/in @ density } (B_P)\right]$$

$$= (76)\left[\begin{array}{l}\text{Look up on rotor magnetization curve}\\ \text{given in (18) @ density (103a)}\end{array}\right]$$

(111)	ϕ_{SH}	FLUX IN SHAFT AND END PLATES - at no load.
(113)	B_{SH}	FLUX DENSITY OF SHAFT - at no load.
(114)	F_{SH}	AMPERE TURNS DROP IN SHAFT AT B_S
(118)	ϕ_5	LEAKAGE FLUX ACROSS COIL AT NO LOAD (Kilolines)

(111) ϕ_{SH}

FLUX IN SHAFT AND END PLATES - at no load.

$$\phi_{SH} = (\phi_{PT}) \frac{(P)}{2} + \phi_7 + \phi_5$$

$$= (102a) \frac{(6)}{2} + (99) + (118)$$

NOTE: No provision is made for calculating the density in the end flux plates. Make the plates thick enough that the periphery of the pole at its base times the thickness of the plate is equal to the cross-sectional area of the pole at its junction with the plate.

(113) B_{SH}

FLUX DENSITY OF SHAFT - at no load.

$$B_{SH} = \frac{(\phi_{SH})}{(a_s)} = \frac{(111)}{(113)}$$

Where $a_s = \frac{\pi (d_s)^2}{4} = \frac{\pi (78)^2}{4}$

(114) F_{SH}

AMPERE TURNS DROP IN SHAFT AT B_S

$$F_{SH} = l_{SH} \left[NI/in \ @ \ density \ (B_{SH}) \right]$$

$= (78)$ [Look up on shaft magnetization curve given in (18) at density (113)]

(118) ϕ_5

LEAKAGE FLUX ACROSS COIL AT NO LOAD (Kilolines)

$$\phi_5 = P_5 \left[2(F_g) + 2(F_T) + (F_c) + 2(F_p) \right] \times 10^{-3}$$

$$= (84) \left[2(96) + 2(97) + (98) + 2(104a) \right] \times 10^{-3}$$

(127)	F_{NL}	TOTAL AMPERE TURNS - at no load. The total ampere turns per pole required to produce rated voltage at no load. $$F_{NL} = \left[2(F_g)+2(F_S)+2(F_P)+(F_{SH})\right] = \left[(96)+(98a)+(104a)+(114\right.$$
(127a)	I_{FNL}	NO LOAD FIELD CURRENT $$I_{FNL} = \frac{F_{NL}}{N_F} = \frac{(127)}{(146)}$$
(127b)	E_{FNL}	NO LOAD FIELD VOLTS PER COIL $$E_{FNL} = (I_{FNL})\,(R_{F(cold)})$$ $$= (127a)(154)$$
(127c)	S_F	CURRENT DENSITY IN FIELD CONDUCTOR - At no load
(128)	A	AMPERE CONDUCTORS per inch
(129)	X	REACTANCE FACTOR
(130)	X_ℓ	LEAKAGE REACTANCE of the stator

$$X_\ell = (X)\left[(\lambda_i) + (\lambda_e) + (\lambda_z)\right]$$

$$= (129)\left[(62) + (64) + (64a)\right]$$

λ_z is explained under item (64a) and should be zero in most designs.

(131)	x_{ad}	REACTANCE - direct axis
(132)	X_{aq}	REACTANCE - quadrature axis
(133)	X_d	SYNCHRONOUS REACTANCE
(134)	X_q	SYNCHRONOUS REACTANCE - quadrature axis
(145)	V_r	PERIPHERAL SPEED
(146)	N_F	NUMBER OF FIELD TURNS
(147)	ℓ_{tF}	MEAN LENGTH OF FIELD TURN

(148)	--	FIELD CONDUCTOR DIA OR WIDTH in inches
(149)	--	FIELD CONDUCTOR THICKNESS in inches - Set this item = 0. for rouna conductor.
(150)	$X_f{}^oC$	FIELD TEMP IN ^oC
(151)	ρ_f	RESISTIVITY of field conductor @ 20°C in micro ohm-inches.
(152)	ρ_f (hot)	RESISTIVITY of field conductor at $X_f{}^oC$
(153)	a_{cf}	CONDUCTOR AREA OF FIELD WINDING
(154)	R_f (cold)	COLD FIELD RESISTANCE @ 20°C $R_f \text{ (cold)} = (\rho_f) \frac{(N_f)\ (\ell_{tf}) \times 10^{-6}}{(a_{cf})} = (151) \frac{(146)(147) \times 10^{-6}}{(153)}$
(155)	R_f (hot)	HOT FIELD RESISTANCE - Calculated at $X_f{}^oC$ (103) $R_f \text{ (hot)} = (\rho_{f \text{ hot}}) \frac{(N_f)\ (\ell_{tf}) \times 10^{-6}}{(a_{cf})} = (152) \frac{(146)(147) \times 10^{-6}}{(153)}$
(156)	--	WEIGHT OF FIELD COIL in lbs. #'s of copper = $.321(N_f)(\ell_{tf})(a_{cf})$ = .321(146) (147)(153) Also refer to note given in item (65).
(157)	--	WEIGHT OF ROTOR IRON
(160)	X_F	FIELD LEAKAGE REACTANCE

(160a)	P_e	ROTOR LEAKAGE PERMEANCE
		$$P_e = P\left[P_1 + P_2 + P_3 + P_4\right]$$ $$= (6)\left[(80) + (81) + (82) + (83)\right]$$
(161)	L_f	FIELD SELF INDUCTANCE
		$$L_f = (N_f)^2 (\ell)\quad (p)\left[(C_p)(\lambda_a)\frac{\pi}{2} + (\lambda_f)\right] \times 10^{-8}$$ $$= (99)^2(13)\quad (6)\left[(73)(70c)\frac{\pi}{2} + (161f)\right] \times 10^{-8}$$
(161f)	λ_F	ROTOR LEAKAGE PERMEANCE per inch of stator stack
		$$\lambda_F = \frac{P_e}{(\ell)(P)} = \frac{(160a)}{(13)(6)}$$
(166)	X'_{du}	UNSATURATED TRANSIENT REACTANCE
(167)	X'_d	SATURATED TRANSIENT REACTANCE
(168)	X''_d	SUBTRANSIENT REACTANCE in direct axis
		$$X''_d = (X'_d) = (167)$$
(169)	X''_q	SUBTRANSIENT REACTANCE in quadrature axis
		$$X''_q = (X_q) = (134)$$
(170)	X_2	NEGATIVE SEQUENCE REACTANCE
(172)	X_0	ZERO SEQUENCE REACTANCE
(173)	K_{xo}	
(175)	λ_{Bo}	$$\lambda_{Bo} = \frac{(K_{xo})}{(K_p)^2}\left[.07(\lambda_a)\right] = \frac{(173)}{(44)^2}\left[.07(70c)\right]$$

(176)	T'_{do}	OPEN CIRCUIT TIME CONSTANT
(177)	T_a	ARMATURE TIME CONSTANT
(178)	T'_d	TRANSIENT TIME CONSTANT
(179)	T''_d	SUBTRANSIENT TIME CONSTANT
(180)	F_{SC}	SHORT CIRCUIT AMPERE TURNS $= (X_d)\ 2(F_g) =$ (133) 2 (96)
(181)	SCR	SHORT CIRCUIT RATIO
(182)	I^2R_F	FIELD I^2R
(183)	F&W	FRICTION & WINDAGE LOSS
(184)	W_{TNL}	STATOR TEETH LOSS
(185)	W_c	STATOR CORE LOSS
(186)	W_{NPL}	POLE FACE LOSS
(187)	K_1	
(188)	K_2	
(189)	K_3	
(190)	K_4	
(191)	K_5	
(192)	K_6	

(194)	I^2R	<u>STATOR I^2R</u> - at no load.
(195)	--	<u>EDDY LOSS</u> - at no load.
(196)	--	<u>TOTAL LOSSES</u> - at no load. Sum of all losses. Total losses = (Field I^2R) + (F&W) + (Stator Teeth Loss) + (Stator Core Loss) + (Pole Face Loss) = (182) + (183) + (184) + (185) + (186)
(196a)	$\phi_{\ell\ell}$	<u>LEAKAGE FLUX PER POLE</u> at 100% load
(198)	e_d	
(193a)	θ	
(207)	ϕ_{7L}	<u>STATOR TO ROTOR FLUX LEAKAGE</u> at full load. $\phi_{7L} = (P_7)\left[(e_d)(F_g) + (F_{PL}) + (F_T)\left[1 + (\cos\theta)\right] + (F_c)\right] \times 10^{-3}$ $= (86)\left[(198)(96) + (213c) + (97)\left[1 + (9)\right] + (98)\right] \times 10^{-3}$
(213)	ϕ_{PL}	<u>FLUX PER POLE</u> at 100% load
(213a)	ϕ_{PTL}	<u>TOTAL FLUX PER POLE</u> at 100% load $\phi_{PTL} = \phi_{PL} + \frac{2(\phi_{\ell\ell})}{(P)} = (213) + \frac{2(196a)}{(6)}$
(213b)	B_{PL}	<u>FLUX DENSITY AT BASE OF POLE</u> at 100% load

(213c)	F_{PL}	AMPERE TURNS PER POLE at 100% load
		$F_{PL} = \ell_p \left[\text{NI/in @ density } (B_{PL}) \right]$
		$= (76) \left[\text{Look up ampere turns/inch on rotor magnetization curve given in (18) at density (213b)} \right]$
(226)	$\emptyset_{5L}$	LEAKAGE FLUX ACROSS COIL AT FULL LOAD (Kilolines)
		$\emptyset_{5L} = P_5 \left[2e_d\, F_g + 2F_{PL} + 2F_T\,(1 + \cos\theta) + F_c \right] 10^{-3}$
		$= (84) \left[2(198)(96) + 2(213c) + 2(97)\left(1 + (9)\right) + (98) \right] \times 10^{-3}$
(231a)	$\emptyset_{SHL}$	$= \emptyset_{PTL}\,\frac{(P)}{2} + (\emptyset_{7L}) + (\emptyset_{5L}) = (213a)\,\frac{(6)}{2} + (207) + (226)$
(232)	B_{SHL}	SHAFT FLUX DENSITY at full load.
		$B_{SL} = \frac{(\emptyset_{SHL})}{(a_s)} = \frac{(231a)}{(113)}$
(233)	F_{SHL}	AMPERE TURN DROP IN SHAFT at full load
		$F_{SHL} = \ell_{SH} \left[\text{NI/in on shaft magnetization curve at density } (B_{SHL}) \right]$
		$= (78) \left[\text{Look up on shaft magnetization curve given in (18) at density (232)} \right]$

(236)	F_{FL}	TOTAL AMPERE TURNS PER POLE at 100% load - The tot ampere turns per pole required to produce rated lc
		$F_{FL} = 2\left[(e_d)(F_g)+\left[1 + (\cos \theta)\right](F_T)+(F_c)+(F_{PL})\right]+(F_{SHL})$
		$= 2\left[(198)(96)+\left[1 + (9)\right](97)+(98)+(213c)\right]+(233)$
(237)	I_{FFL}	FIELD CURRENT at 100% load
		$I_{FFL} = (F_{FL})/(N_F) = (236)/(146)$
(238)	E_{FFL}	FIELD VOLTS at 100% load
(239)	S_{FL}	CURRENT DENSITY at 100% load
(241)	I^2R_{FL}	FIELD I^2R at 100% load
(242)	W_{TFL}	STATOR TEETH LOSS at 100% load
(243)	W_{PFL}	POLE FACE LOSS at 100% load
(245)	I^2R_L	STATOR I^2R at 100% load
(246)	--	EDDY LOSS
(247)	--	TOTAL LOSSES at 100% load - sum of all losses at 100% lc
		Total Losses = (Field I^2R) + (F&W) + (Stator Teeth Loss) + (Stator Core Loss) + (Pole Face Loss) + (Stator I^2R) + (Eddy Loss)
		= (241) + (183) + (242) + (185) + (243) + (245) + (246)
(248)	--	RATING IN KILOWATTS at 100% load

(249)	--	<u>RATING AND LOSSES</u>
(250)	--	<u>% LOSSES</u>
(251)	--	<u>% EFFICIENCY</u>
		These items can be recalculated for any load condition by simply inserting the values that correspond to the % load being calculated.
		Values for F&W (183) and W_C (Stator Core Loss) (185) do not change with load.

INPUT AUXILIARY DATA SHEET

Auxiliary information taken from the design manuals to be used in conjunction with input sheets for convenience.

A. All dimensions for lengths, widths, and diameters are to be given in inches.

B. Resistivity inputs, Items (141) and (151) are to be given in micro-ohm-inches.

The following items along with an explanation of each are tabulated here for convenience. For complete explanation of each item number, refer to design manuals.

Item No.	Explanation
(9)	Power factor to be given in per unit. For example for 90% P.F., insert .90.
(9a)	Adjustment Factor - For P.F. < .95 insert 1.0 For P.F. > .95 insert 1.05
(10)	Optional Load Point -- Where load data output is required at a point other than those given as standard on the input sheet. Example: For load data output at 155% load, insert 1.55.
(14)	Number of radial ducts in stator.
(15)	Width of radial ducts used in Item (14).
(18)	Magnetization curve of material used to be submitted as defined in Item (18).
(19)	Watts/Lb. to be taken from a core loss curve at the density given in Item (20) (Stator).
(20)	Density in kilolines/in^2. This value must correspond to density used to pick Item (19) usually use 77.4 Kl/in^2.
(21)	Type of slot - For open slot Type A, insert 1.0. For partially open slot Type B with constant slot width, insert 2.0. For partially open slot Type C with constant tooth width, insert 3.0. For round slot Type D, insert 4.0. For additional information, refer to figure adjacent to input sheet which shows a picture of each slot.
(22)	For stator slot dimension - for dimensions that do not apply to the slot insert 0.0. Use Table below as guide for input.

Symbol	Item	Slot Type 1	2	3	4
b_o	(22)	0.0	*	*	[illegible]
b_1	↓	0.0	0.0	*	[illegible]
b_2		0.0	0.0	*	0.0
b_3		0.0	0.0	*	0.0
b_s		*	*	*	*
h_o		0.0	*	*	*
h_1		*	*	*	0.0
h_2		*	0.0	0.0	0.0
h_3		*	*	0.0	0.0
h_s		*	*	*	*
h_t		0.0	*	*	0.0
h_w	↓	0.0	*	*	0.0

* = insert actual value.

$\underline{b_1 + b_3}$

Item No. — Explanation

(28) Type of winding - for wye connected winding insert 1.0.
for delta connected winding insert 0.0.

(29) Type of coil - for formed wound (rect. wire), insert 1.0.
for random wound (round wire) insert 0.0.

(30) Slots spanned - Example - for slot span of 1-10, insert 9.0.

(33) For round wire insert diameter. For rectangular wire insert wire width.

(34) Strands per conductor in depth only.

(34a) Total strands per conductor in depth and width.

(35) Diameter of coil head forming pin. Insert .25 for stator O.D. < 8 inches;
Insert .50 for stator O.D. > 8 in.

(37) Use vertical height of strand for round wire, insert 0.0.

(38) Distance between centerline of strands in depth.

(39) Stator strand thickness -- use narrowest dimension of the two dimensions given for a rectangular wire. For round wire insert 0.0.

(40) Stator slot skew in inches.

(42a) Phase belt angle - for 60° phase belt, insert 60°.
for 120° phase belt, insert 120°.

(48) See explanation of items (71), (72), (73), (74) and (75). Same applies here.

(87) When no load saturation output data is required at various voltages, insert 1.0.
When no load saturation information is not required, insert 0.0.

(137) Damper bar thickness -- use damper bar slot height for rectangular bar. For round bar insert 0.0.

(138) Number of damper bars per pole.

(140) Damper bar pitch in inches.

(148) For round wire insert diameter. For rectangular wire insert wire width.

(149) For rectangular wire insert wire thickness. For round wire insert 0.0.

(187) Pole face loss factor. For rotor lamination thickness .028 in. or less, insert 1.17.
For rotor lamination thickness .029 in. to .063 in. insert 1.75.
For rotor lamination thickness .064 in. to .125 insert 3.5.
For solid rotor insert 7.0.

(71)
(72)
(73)
(74) If the values of these constants are available, insert the actual number. If they are not available, insert 0.0 and the computer will calculate the values and record them on the output.

INSIDE-COIL, STATIONARY-COIL LUNDELL GENERATOR

COMPUTER DESIGN - - - - - - - (INPUT)

MODEL ______ EWO ______ DESIGN NO (1) ______

Section	No.	Symbol	Description	Value
PARAMETERS	(2)	KVA	GENERATOR KVA	
	(3)	E	LINE VOLTS	
	(4)	E_{ph}	PHASE VOLTS	
	(5)	m	PHASES	
	(5a)	f	FREQUENCY	
	(6)	p	POLES	
	(7)	RPM	RPM	
	(8)	I_{ph}	PHASE CURRENT	
	(9)	PF	POWER FACTOR	
	(9a)	K_c	ADJ. FACTOR	
	(10)		OPTIONAL LOAD POINT	
STATOR STACK	(11)	d	STATOR I.D.	
	(12)	D	STATOR O.D.	
	(13)		GROSS CORE LENGTH	
	(14)	n_v	NO. OF DUCTS	
	(15)	b_v	WIDTH OF DUCT	
	(16)	K_i	STACKING FACTOR (STATOR)	
	(19)	k	WATTS/LB.	
	(20)	B	DENSITY	
STATOR SLOT	(21)		TYPE OF SLOT	
	(22)	b_o	SLOT OPENING	
	(22)	b_1	SLOT WIDTH TOP	
	(22)	b_2		
	(22)	b_3		
	(22)	b_s	SLOT WIDTH	
	(22)	h_o		
	(22)	h_1		
	(22)	h_2		
	(22)	h_3		
	(22)	h_s	SLOT DEPTH	
	(22)	h_t		
	(22)	h_w		
	(23)	Q	NO. OF SLOTS	
STATOR WINDING	(28)		TYPE OF WDG.	
	(29)		TYPE OF COIL	
	(30)	n_s	CONDUCTORS/SLOT	
	(31)	y	SLOTS SPANNED	
	(32)	c	PARALLEL CIRCUITS	
	(33)		STRAND DIA. OR WIDTH	
	(34)	N_{st}	STRANDS/CONDUCTOR IN DEPTH	
	(34a)	N'_{st}	STRANDS/CONDUCTOR	
	(39)		STATOR STRAND T'KNS.	
	(35)	d_b	DIA. OF PIN	
	(36)	ℓ_{e2}	COIL EXT. STR. PORT	
	(37)	h_{st}	UNINS. STRD. HT.	
	(38)	h'_{st}	DIST. BTWN. C_L OF STD.	
	(42a)		PHASE BELT ANGLE	
	(40)	τ_{sk}	STATOR SLOT SKEW	
	(50)	X °C	STATOR TEMP °C	
	(51)	ρ_s	RES'TVY STA. COND. @ 20° C	
GAP	(78)	ℓ_{g3}	AXIAL LENGTH OF GAP (g_3)	
	(78)	d_{g3}	DIAMETER AT GAP (g_3)	
	(78)	d_{g2}	DIAMETER AT GAP (g_2)	
	(59)	g	MAIN AIR GAP	
	(59a)	g_2	AUXILIARY GAP (g_2)	
	(59b)	g_3	AUXILIARY GAP (g_3)	

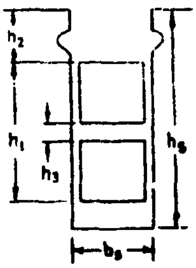
Value	Description	No.	Symbol	Section
	RATIO MAX TO MIN OF FUND	(71)	C_1	CONSTANTS
	WINDING CONSTANT	(72)	C_w	
	POLE CONSTANT	(73)	C_p	
	END EXTENSION ONE TURN	(48)	L_E	
	DEMAGNETIZATION FACTOR	(74)	C_m	
	CROSS MAGNETIZING FACTOR	(75)	C_q	
	POLE EMBRACE	(77)	α_c	
	WIDTH OF POLE (NARROW END)	(76)	b_{P1}	POLE & ROTOR
	WIDTH OF POLE (WIDE END)	(76)	b_{P2}	
	POLE THICKNESS (NARROW END)	(76)	t_{P1}	
	POLE THICKNESS (WIDE END)	(76)	t_{P2}	
	POLE LENGTH	(76)	ℓ_p	
	ROTOR DIAMETER	(11a)	d_r	
	WEIGTH OF ROTOR IRON	(157)	(-)	
	POLE FACE LOSS FACTOR	(187)	K_1	
	SHAFT O.D. (FLUX CARRYING PART	(78)	d_s	SHFT
	SHAFT LENGTH " " "	(78)	ℓ_{sh}	
	PERM OF LEAKAGE PATH 1	(80)	P_1	PERMEANCE
	PERM OF LEAKAGE PATH 2	(81)	P_2	
	PERM OF LEAKAGE PATH 3	(82)	P_3	
	PERM OF LEAKAGE PATH 4	(83)	P_4	
	PERM OF LEAKAGE PATH 5	(84)	P_5	
	PERM OF LEAKAGE PATH 7	(86)	P_7	
	LENGTH OF PERM PATH 1	(80a)	ℓ_1	
	LENGTH OF PERM PATH 2	(81a)	ℓ_2	
	LENGTH OF PERM PATH 3	(82a)	ℓ_3	
	OUTSIDE DIA. OF FIELD COIL	(78)	d_{co}	FIELD
	LENGTH OF FIELD COIL	(76)	ℓ_{co}	
	NO. OF FIELD TURNS/COIL	(146)	N_F	
	MEAN LENGTH OF FLD. TURN	(147)	ℓ_{tf}	
	FLD. COND. DIA. OR WIDTH	(148)		
	FLD. COND. THICKNESS	(149)		
	FLD. TEMP IN °C	(150)	X_f °C	
	RESISTIVITY OF FLD. COND @ 20°	(151)	ρ_f	
	NO LOAD SAT.	(87)		
	FRICTION & WINDAGE	(183)	(F&W)	
	SPECIAL PERMEANCE	64a	λ_z	
	STATOR LAM MATERIAL	(10)		MATR'L
	POLE MATERIAL	(18)		
	SHAFT MATERIAL	(18)		

STATOR SLOT	POLE
DAMPER SLOT	REMARKS

DESIGNER ______ DATE ______

REV. B

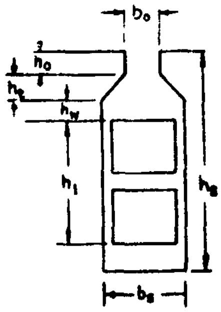
(a) Open Slots



TYPE 1

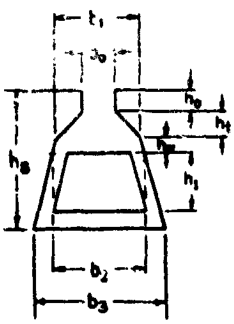
(Type 5 is an open slot with 1 conductor per slot)

(b) Constant Slot Width



TYPE 2

(c) Constant Tooth Width

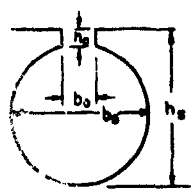


TYPE 3

b_s for type 3 is

$$b_s = \left(\frac{b_1 + b_3}{2}\right)$$

(d) Round Slots



TYPE

INSIDE-COIL, STATIONARY-COIL LUNDELL GENERATOR
SUMMARY OF DESIGN CALCULATIONS - - - - - - - - (OUTPUT)

MODEL NO. ____________ EWO ____________ DESIGN NO. ____________

Group	No.	Symbol	Item			Item	No.	Symbol	Group
STATOR	(17)	(ℓ_s)	SOLID CORE LENGTH			CARTER COEFFICIENT	(67)	(K_s)	CONSTANTS
	(24)	(h_c)	DEPTH BELOW SLOT			EFFECTIVE AIR GAP	(69)	(g_e)	
	(26)	(τ_s)	SLOT PITCH			FUND/MAX OF FLD. FLUX	(71)	(C_1)	
	(27)	(τ_s 1/3)	SLOT PITCH 1/3 DIST. UP			WINDING CONST.	(72)	(C_w)	
	(42)	(K_{sk})	SKEW FACTOR			POLE CONST.	(73)	(C_p)	
	(43)	(K_d)	DIST. FACTOR			END. EXT. ONE TURN	(48)	(LE)	
	(44)	(K_p)	PITCH FACTOR			DEMAGNETIZING FACTOR	(74)	(C_M)	
	(45)	(n_e)	EFF. CONDUCTORS			CROSS MAGNETIZING FACTOR	(75)	(C_q)	
	[illegible]	(a_c)	COND. AREA			AMP COND IN	(128)	(A)	REACTANCE
	[illegible]	(S_a)	CURRENT DENSITY (STA.)			REACTANCE FACTOR	(129)	(X)	
	(49)	(ℓ_t)	1/2 MEAN TURN LENGTH			LEAKAGE REACTANCE	(130)	(X_ℓ)	
	(53)	(R_{ph})	COLD STA. RES. @ 20° C			REACTANCE OF ARMATURE REACTION	(131)	(X_{ad})	
	(54)	(R_{ph})	HOT STA. RES. @ X° C				(132)	(X_{aq})	
	(55)	(EF_{top})	EDDY FACTOR TOP			SYN REACT DIRECT AXIS	(133)	(X_d)	
	(56)	(EF_{bot})	EDDY FACTOR BOT			SYN REACT QUAD AXIS	(134)	(X_q)	
	(62)	(λ_1)	STATOR COND. PERM.			FIELD LEAKAGE REACT	(160)	(X_f)	
	(63)	(λ_e)	END PERM.			FIELD SELF INDUCTANCE	(161)	(L_f)	
	(65)	( )	WT. OF STA COPPER			UNSAT. TRANS. REACT	(166)	(X'_{du})	
	(66)	( )	WT. OF STA. IRON			SAT. TRANS. REACT	(167)	(X'_d)	
	(41)	(τ_p)	POLE PITCH			SUB. TRANS. REACT DIRECT AX.	(168)	(X''_d)	
	(157)	(–)	WT. OF ROTOR IRON			SUB. TRANS REACT QUAD AX.	(169)	(X''_q)	
	(145)	(V_r)	PERIPHERAL SPEED			NEG SEQUENCE REACT	(170)	(X_2)	
FIELD	(153)	(a_{CF})	FLD. COND. AREA			ZERO SEQUENCE REACT	(172)	(X_0)	
	(154)	(R_F)	COLD FLD. RES. @ 20° C			OPEN CIR. TIME CONST.	(176)	(T_{do})	TIME CONST.
	(155)	(R_F)	HOT FLD. RES. @ X° C			ARM TIME CONST.	(177)	(T_a)	
	(156)	(–)	WT OF FLD. COPPER			TRANS TIME CONST.	(178)	(T'_d)	
PERMEANCE	(80)	(P1)	PERM OF LEAKAGE PATH 1			SUB TRAN TIME CONST.	(179)	(T''_d)	
	(81)	(P2)	PERM OF LEAKAGE PATH 2			TOTAL FLUX	(90)	(ϕ_T)	MAGNETIZATION
	(82)	(P3)	PERM OF LEAKAGE PATH 3			FLUX PER POLE	(93)	(ϕ_p)	
	(83)	(P4)	PERM OF LEAKAGE PATH 4			GAP DENSITY (MAIN)	(95)	(B_g)	
	(84)	(P5)	PERM OF LEAKAGE PATH 5			TOOTH DENSITY	(91)	(B_t)	
	(86)	(P7)	PERM OF LEAKAGE PATH 7			CORE DENSITY	(94)	(B_c)	
	(180)	(FSC)	SHORT CIR NI			TOOTH AMPERE TURNS	(97)	(F_t)	
	(181)	(SCR)	SHORT CIR RATIO			CORE AMPERE TURNS	(98)	(F_c)	
						GAP AMPERE TURNS (MAIN)	(96)	(F_g)	

PERCENT LOAD	0		100	50	200	OPTIONAL
(ϕ_ℓ) (100a) LEAKAGE FLUX		($\phi_{\ell f}$) (197a)				
(ϕ_{pt}) (102a) TOTAL FLUX/POLE		(ϕ_{ptl}) (213a)				
(B_p) (103a) POLE DENSITY		(B_{pl}) (213b)				
(B_{g2}) (122) AUX GAP(g2) DENSITY		(B_{g2fl}) (224)				
(B_{g3}) (119) AUX GAP(g3) DENSITY		(B_{g3fl}) (230)				
(B_{sh}) (113) SHAFT DENSITY		(B_{shl}) ([illegible])				
(F_{nl}) (127) TOTAL NI		(F_{fl}) (236)				
(I_{fnl}) (127a) FIELD AMPERES		(I_{ffl}) (237)				
(S_f) (127c) CUR. DEN. FLD.		( ) (239)				
(E_{fnl}) (127b) FIELD VOLTS		(E_{ffl}) (238)				
(W_c) (185) STA CORE LOSS		(W_c) (185)				
(W_{tnl}) (184) STA TOOTH LOSS		(W_{tfl}) (242)				
(I^2R_a) (194) STATOR CU LOSS		(I^2R_a) (245)				
(–) (195) EDDY LOSS		(–) (246)				
(W_{pnl}) (186) POLE FACE LOSS		(W_{pfl}) (243)				
(I^2R_f) (182) FIELD COIL LOSS		(I^2R_f) (241)				
(F&W) (183) F&W LOSS		(F&W) (183)				
(–) (196) TOTAL LOSSES		(–) (247)				
(–) (–) PERCENT EFF.		(–) (251)				

(Left margin: VARIABLE LOAD)

DESIGNER ____________ DATE ____________

REV. A

INSIDE-COIL, STATIONARY-COIL LUNDELL
NO LOAD SATURATION OUTPUT SHEET

ITEMS / % VOLTS	(3) (E) VOLTS (100a) (ϕ_l) LEAKAGE FLUX	(95) (B_g) MAIN GAP DENSITY (102) (ϕ_{pt}) TOTAL FLUX/POLE	(122) (B_{g2}) DENSITY (g2) (103a) (B_p) POLE DENSITY	(119) (B_{g3}) DENSITY (g3) (113) (B_{sh}) SHAFT DENSITY	(94) (B_c) STA CORE DENSITY (127) (F_{nl}) TOTAL N. I.	(91) (B_t STA TOOTH DE
80%						
90%						
100%						
110%						
120%						
130%						
140%						
150%						
160%						

INSIDE-COIL, STATIONARY-COIL, LUNDELL, A.C. GENERATOR

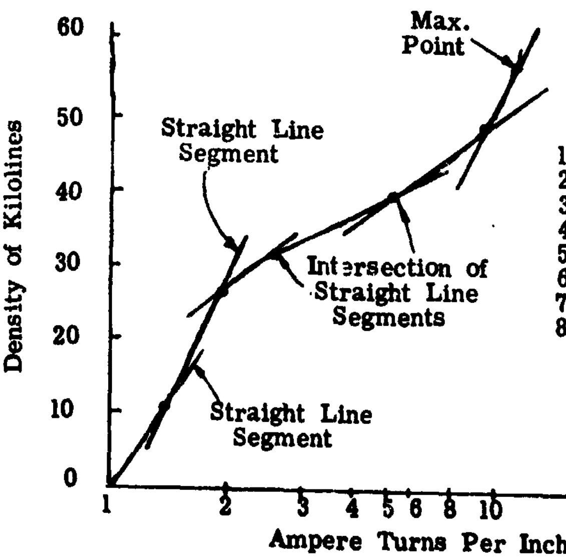
(1)	--	DESIGN NUMBER
(2)	KVA	GENERATOR KVA
(3)	E	LINE VOLTS
(4)	E_{PH}	PHASE VOLTS
(5)	m	PHASES
(5a)	f	FREQUENCY
(6)	P	POLES
(7)	RPM	SPEED
(8)	I_{PH}	PHASE CURRENT
(9)	P. F.	POWER FACTOR
(9a)	K_c	ADJUSTMENT FACTOR
(10)	--	LOAD POINTS
(11)	d	STATOR PUNCHING I.D.
(11a)	d_r	ROTOR O.D.
(12)	D	PUNCHING O.D.
(13)	ℓ	GROSS STATOR CORE LENGTH
(14)	n_v	RADIAL DUCTS
(15)	b_v	RADIAL DUCT WIDTH
(16)	K_i	STACKING FACTOR
(17)	ℓ_s	SOLID CORE LENGTH

(18)

MATERIAL - This input is used in selecting the proper magnetization curves for stator, pole, shaft; when different materials are used. Separate spaces are provided on the input sheet for each section mentioned above. Where curves are available on card decks, used the proper identifying code. Where card decks are not available submit data in the following manner:

The magnetization curve must be available on semi-log paper. Typical curves are shown in this manual on Curves F15 and F16. Draw straight line segments through the curve starting with zero density. Record the coordinates of the points where the straight line segments intersect. Submit these coordinates as input data for the magnetization curve. The maximum density point must be submitted first.

Refer to Figure below for complete sample



Sample Input Data

	Density	NI
1)	55	Max.
2)	0	0
3)	10	1.5
4)	27	1.9
5)	32	2.5
6)	40	4.9
7)	48	9.0
8)	55	12.0

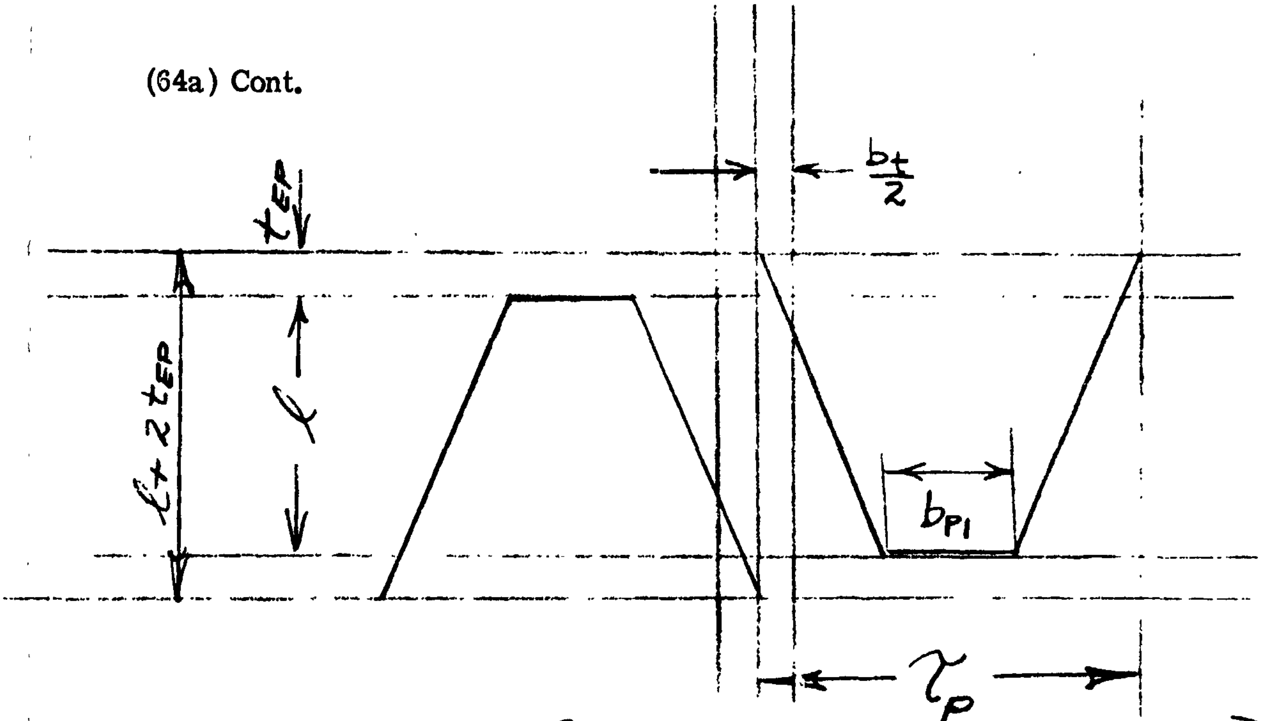
(19)	k	WATTS/LB
(20)	B	DENSITY
(21)		TYPE OF STATOR SLOT
(22)		ALL SLOT DIMENSIONS
(23)	Q	STATOR SLOTS
(24)	h_c	DEPTH BELOW SLOTS
(25)	q	SLOTS PER POLE PER PHASE
(26)	τ_s	STATOR SLOT PITCH
(27)	τ_s 1/3	STATOR SLOT PITCH
(28)	--	TYPE OF WINDING
(29)	--	TYPE OF COIL
(30)	n_s	CONDUCTORS PER SLOT
(31)	Y	THROW
(31a)		PER UNIT OF POLE PITCH SPANNED
(32)	C	PARALLEL PATHS
(33)	--	STRAND DIA. OR WIDTH
(34)	N_{ST}	NUMBER OF STRANDS PER CONDUCTOR IN DEPTH
(34a)	N'_{ST}	NUMBER OF STRANDS PER CONDUCTOR
(35)	d_b	DIAMETER OF BENDER PIN
(36)	ℓ_{e2}	COIL EXTENSION BEYOND CORE
(37)	h_{ST}	HEIGHT OF UNINSULATED STRAND
(38)	h'_{ST}	DISTANCE BETWEEN CENTERLINES OF STRANDS IN DEPTH

(39)	--	STATOR COIL STRAND THICKNESS
(40)	τ_{SK}	SKEW
(41)	τ_P	POLE PITCH
(42)	K_{SK}	SKEW FACTOR
(42a)		PHASE BELT ANGLE
(43)	K_d	DISTRIBUTION FACTOR
(44)	K_p	PITCH FACTOR
(45)	n_e	TOTAL EFFECTIVE CONDUCTORS
(46)	a_c	CONDUCTOR AREA OF STATOR WINDING
(47)	S_S	CURRENT DENSITY
(48)	L_E	END EXTENSION LENGTH
(49)	ℓ_t	1/2 MEAN TURN
(50)	$X_s\ ^oC$	STATOR TEMP ^oC
(51)	ρ_s	RESISTIVITY OF STATOR WINDING
(52)	$\rho_{s\,(hot)}$	RESISTIVITY OF STATOR WINDING
(53)	R_{SPH} (cold)	STATOR RESISTANCE/PHASE
(54)	R_{SPH} (hot)	STATOR RESISTANCE/PHASE
(55)	EF (top)	EDDY FACTOR TOP
(56)	EF (bot)	EDDY FACTOR BOTTOM

(57)	b_{tm}	STATOR TOOTH WIDTH
(57a)	$b_{t\,1/3}$	STATOR TOOTH WIDTH
(58)	b_t	TOOTH WIDTH AT STATOR I.D.
(59)	g	MAIN AIR GAP in inches
(59a)	g_2	AUXILIARY GAP, INNER - in inches
(59b)	g_3	AUXILIARY GAP, OUTER - in inches
(60)	C_X	REDUCTION FACTOR
(61)	K_X	FACTOR TO ACCOUNT FOR DIFFERENCE in phase current in coil sides in same slot.
(62)	λ_i	CONDUCTOR PERMEANCE
(63)	K_E	LEAKAGE REACTIVE FACTOR for end turn
(64)	λ_E	END WINDING PERMEANCE
(64a)	λ_z	SPECIAL LEAKAGE PERMEANCE - For machines having a section of the pole that is approximately a full pole-pitch wide, an additional leakage permeance must be added to the slot and end-turn leakage permeances. This permeance is that of the leakage path from one pole into a tooth top and from tooth top back into the adjacent pole. The leakage

(64a)	Cont'd.	is similar to Zig Zag leakage and by increasing the stator leakage reactance, can reduce the output of the generator significantly. This same leakage can be used to purposely limit the output of the generator and make it current limited. The presence of this additional leakage can be good or bad depending upon what is wanted from the generator. The important thing is for the designer to be aware that it is there. In many cases, the designer should estimate the specific permeances λ_z since the pole base will be more or less than a full pole pitch wide and the following formula will not suffice.

(64a) Cont.



$$\lambda_z = (C_X)\frac{20}{(m)(q)}\left\{\frac{\text{area of pole over tooth when tooth is on centerline between poles}}{2\,\ell\, g}\right\}$$

$$\lambda_z = (C_X)\frac{20}{(m)(q)}\left\{\frac{b_t\,(\tau_p - b_{p1})\,(\ell + 2\,t_{EP})\;\dfrac{(\tau_p - b_{p1})}{\tau_p}}{2\,\ell\;g}\right\}$$

(65)	--	WEIGHT OF COPPER
(66)	--	WEIGHT OF STATOR IRON - in lbs.
(67)	K_s	CARTER COEFFICIENT
(68)	A_g	MAIN AIR GAP AREA
(69)	g_e	EFFECTIVE AIR GAP

(70)	A_{g2}	AREA OF AUXILIARY AIR GAP $A_{g2} = \frac{\pi}{4}(d_{g2})^2 = \frac{\pi}{4}(87)^2$
(70a)	A_{g3}	AREA OF OUTER AUXILIARY AIR GAP $A_{g3} = \pi(d_{g3})(\ell_{g3}) = (87)(87)$
(71)	C_1	THE RATIO OF MAXIMUM FUNDAMENTAL of the field form to the actual maximum of the field form -
(72)	C_W	WINDING CONSTANT
(73)	C_P	POLE CONSTANT
(74)	C_M	DEMAGNETIZING FACTOR - direct axis
(75)	C_q	CROSS MAGNETIZING FACTOR - quadrature axis
(76)		POLE DIMENSION LOCATIONS b_{p2} - width of pole at edge of stator stack (wide end). b_{p1} - width of pole at end (narrow end). t_{p2} - thickness of pole at edge of stator stack. t_{p1} - thickness of pole at end. ℓ_{co} - length of coil. ℓ_p - length of pole.

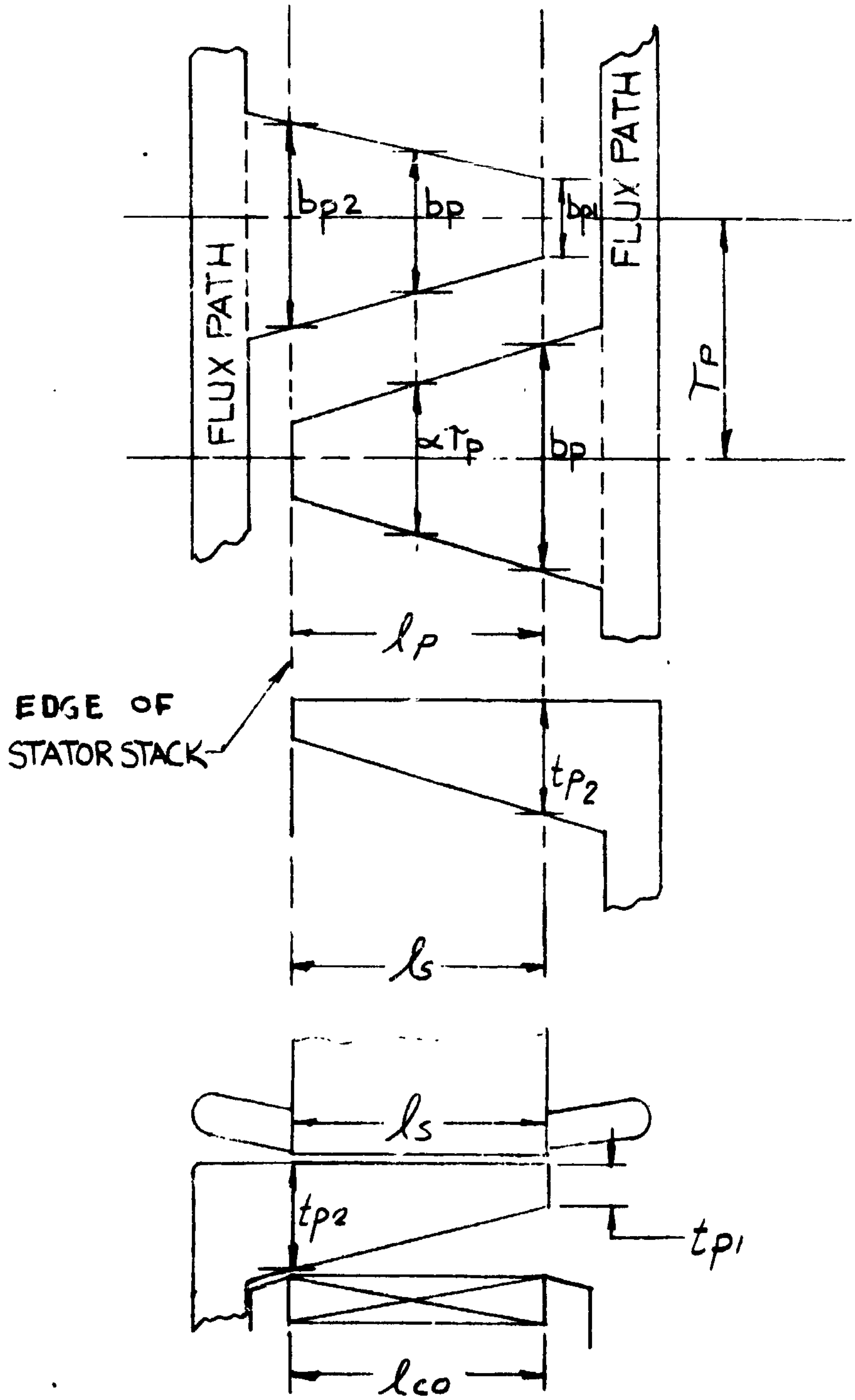

FLUX PATH
FLUX PATH
b_{p2}
b_p
b_{p1}
τ_p
$\alpha\tau_p$
b_p
l_p
EDGE OF
STATOR STACK
t_{p_2}
l_s
l_s
t_{p2}
t_{p1}
l_{co}

Fig. K-2

(77)	α	**POLE EMBRACE** $$\alpha = \frac{(b_{p1}) + (b_{p2})}{2\,(\tau_p)} = \frac{(76) + (76)}{2\,(41)}$$
(77a)		Items immediately following, deal with the calculation of rotor and stator leakage permeances. Illustrations are included to help identify the permeance areas and paths of the leakage fluxes. The computer program will handle the permeance calculations either of two ways:

1) P_1 through P_7 can be calculated by the computer. For this case, insert 0.0 on the input sheet.

2) P_1 through P_7 can be calculated by the designer. For this case, insert the actual calculated value on the input sheet.

Permeance calculations P_1 through P_7 are all based on the equations

$$P = \frac{u\ (\text{area})}{\ell}$$

Where u = 3.19

Area = cross-sectional area perpendicular to ℓ

ℓ = length of permeance leakage path

Many of the equations used in this section are taken from Roter's "Electromagnetic Devices". Refer to the appendix for an explanation of each condition.

(78)

ROTOR AND STATOR DIMENSIONS

ℓ_{g3} - axial length of air gap (g3)

d_{g3} - diameter at air gap (g3)

d_{g2} - diameter of the circle containing flux in gap (g2)

d_s - diameter of shaft (equal to coil inside diameter)

ℓ_{SH} - length of shaft (flux carrying portion)

t_{fp} - thickness of flux plate

d_{oc} - outside diameter of coil

ℓ_{co} - length of coil (axial length)

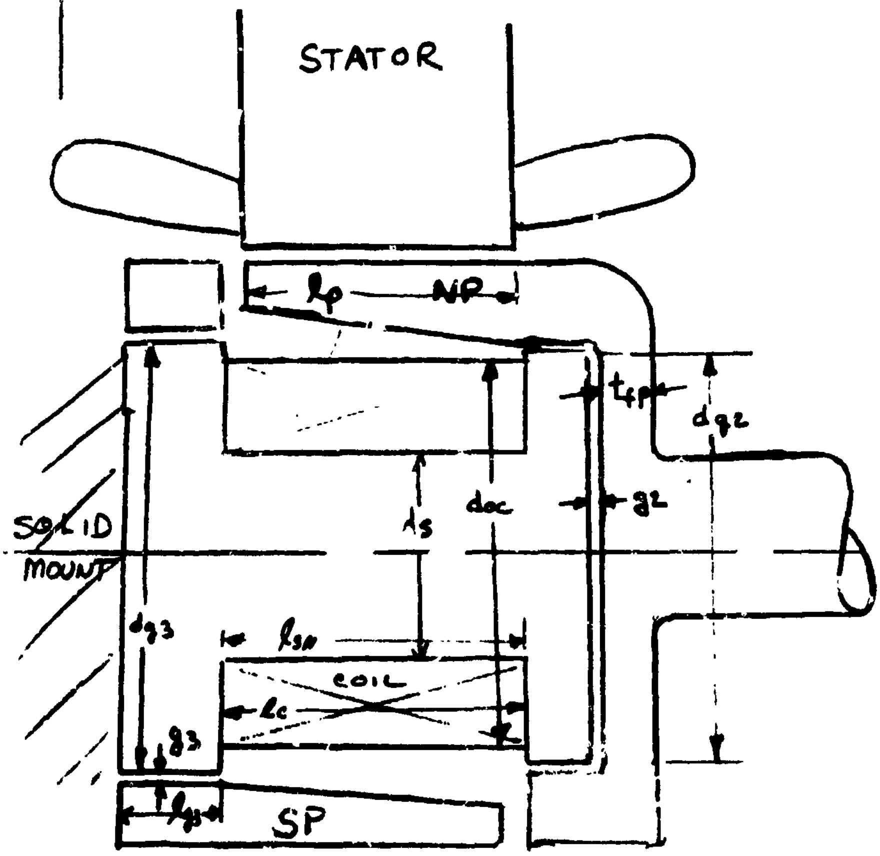


Fig. X-3

(79)	a_p	**POLE AREA** - The effective cross sectional area of the pole. $a_p = (b_{p2})(t_{p2}) = (76)(76)$
(80)	P_1	**POLE HEAD END LEAKAGE** - This input can be either 0.0 or the actual value if available. Refer to item 86 for explanation. See Figure K4 for location. $P_1 = \frac{3.19 (b_{p1})(t_{p1})}{\ell_1} = \frac{3.19 (76)(76)}{(80a)}$
(80a)	ℓ_1	**LENGTH OF PERMEANCE PATH P_1** - ℓ_1 is the length of permeance path P_1 and must be obtained from design layout. Note this value (ℓ_1) must appear as a input when $P_1 = 0.0$
(81)	P_2	**POLE HEAD SIDE LEAKAGE** - This input can be either 0.0 or the actual value if available. Refer to item 86 for explanation. See Figure K4 for location. $P_2 = 3.19 \frac{\left[(t_{p1}) + (t_{p2})\right]}{2} \frac{(\ell_p)}{(\ell_2)}$ $= 3.19 \frac{\left[(76) + (76)\right]}{2} \frac{(76)}{(81a)}$
(81a)	ℓ_2	**LENGTH OF PERMEANCE PATH P_2** - ℓ_2 is the length of permeance path P_2 and must be obtained from design layout. Note: This value (ℓ_2) must appear as an input when $P_2 = 0.0$

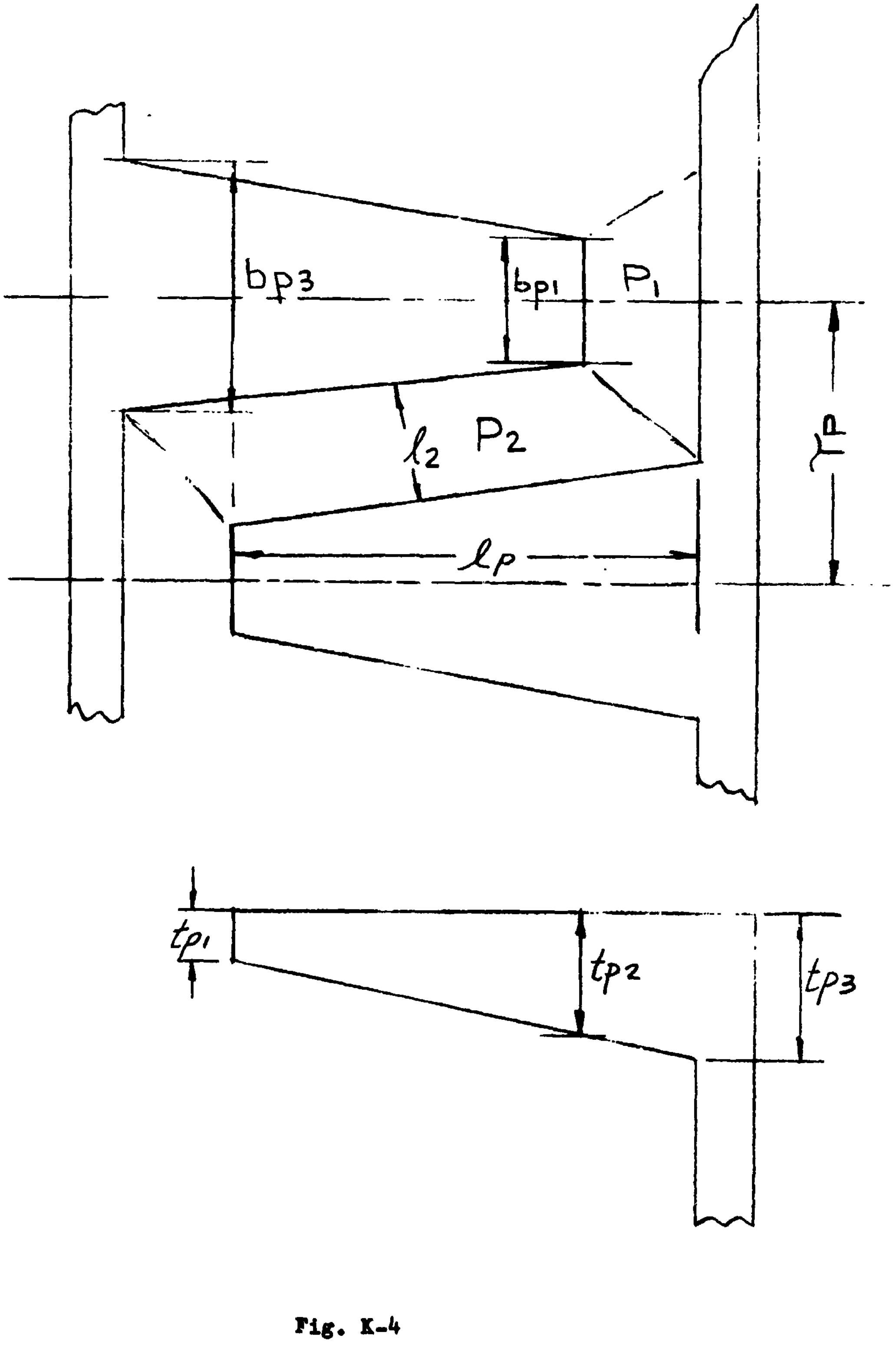


Fig. K-4

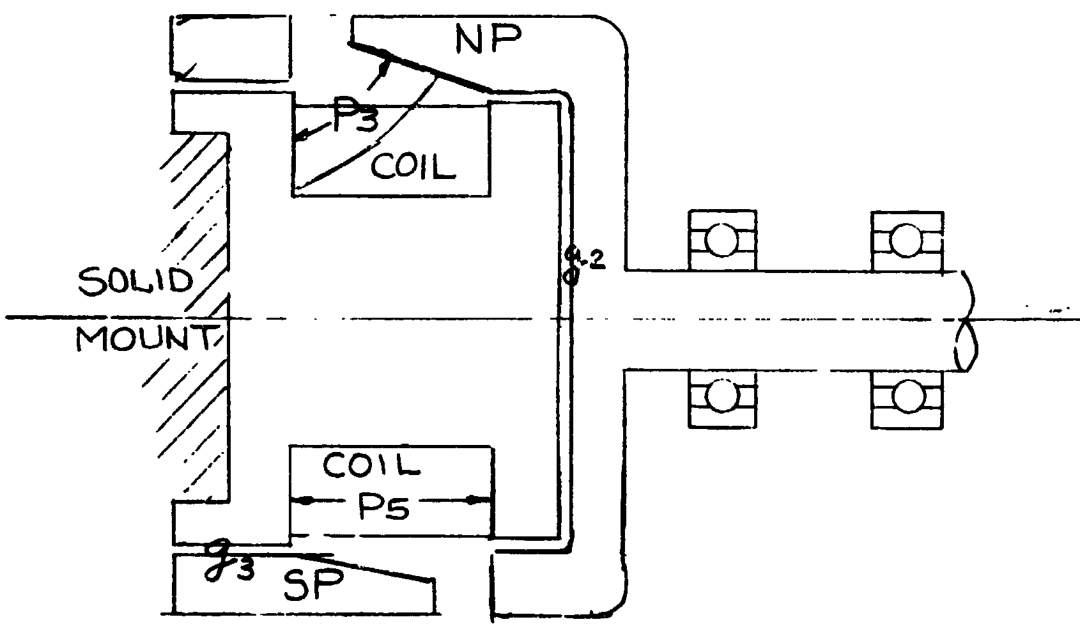


Fig. K-5

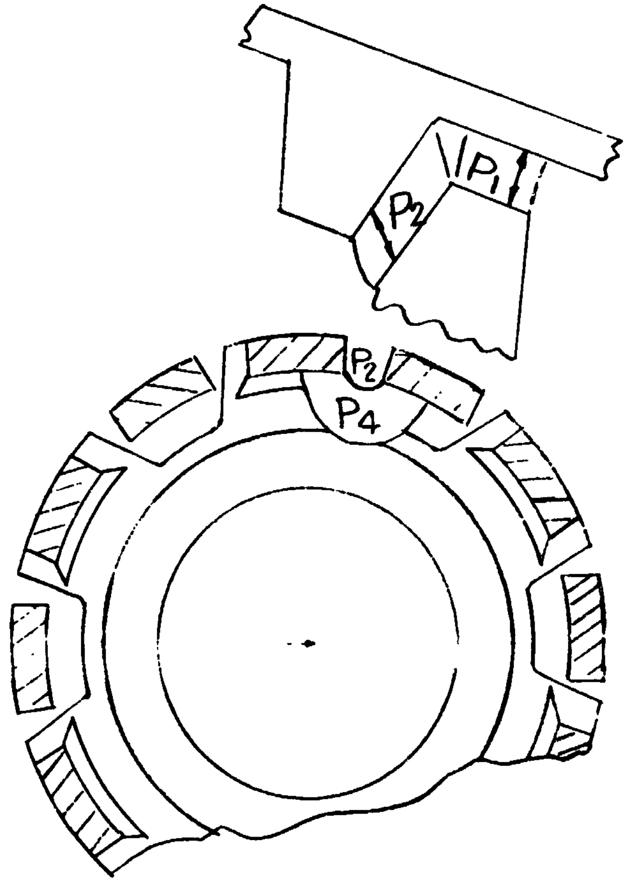
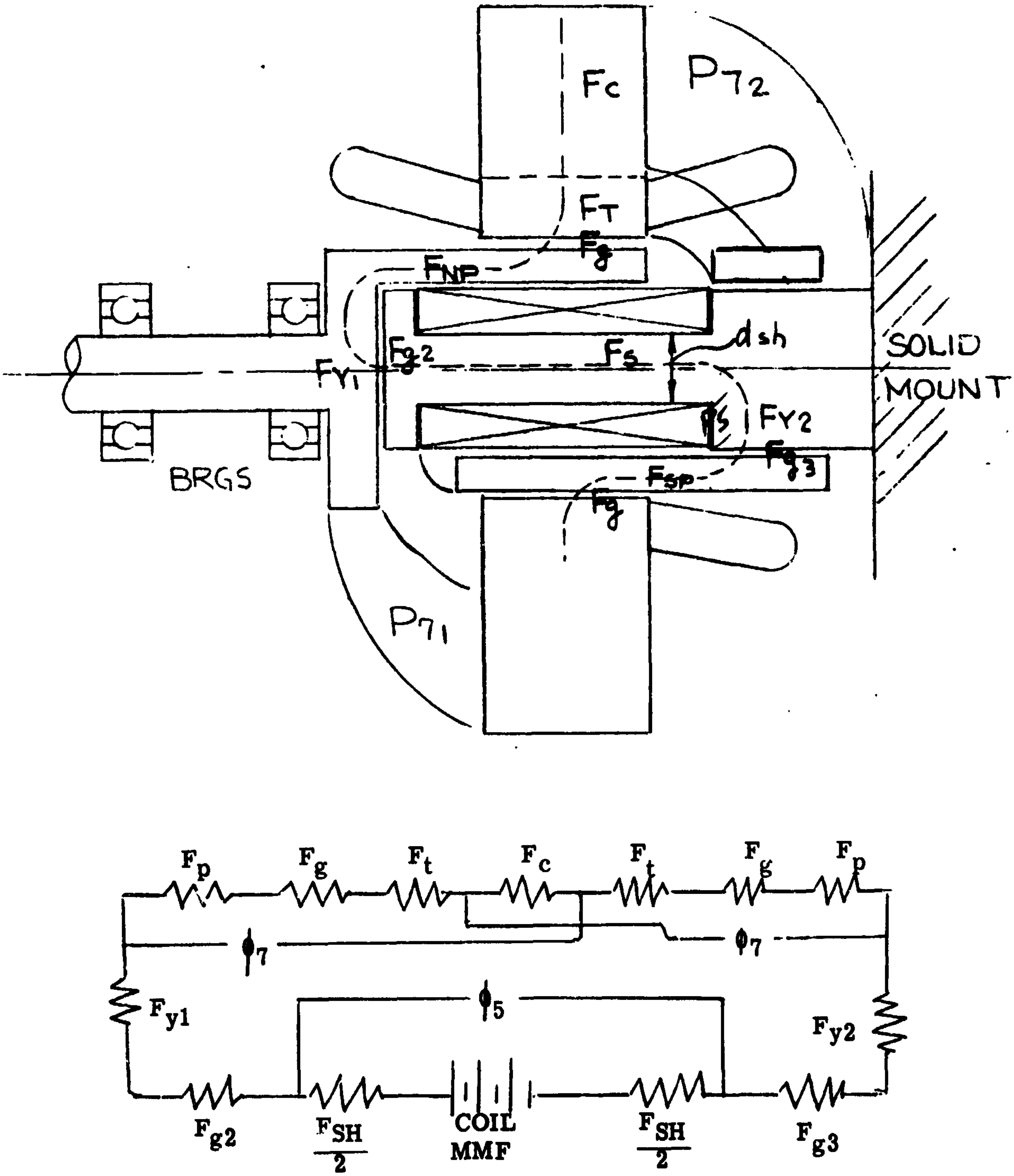


Fig. K-6



Fc
P72
FT
Fg
FNP
dsh
SOLID
MOUNT
Fg2
Fs
FY1
φs
FY2
Fg3
BRGS
FSP
Fg
P71
F_p
F_g
F_t
F_c
F_t
F_g
F_p
ϕ_7
ϕ_7
F_{y1}
ϕ_5
F_{y2}
F_{g2}
$\frac{F_{SH}}{2}$
COIL
MMF
$\frac{F_{SH}}{2}$
F_{g3}

Fig. K-7

(82) P_3 <u>POLE UNDERSIDE TO FLUX PLATE LEAKAGE PERMEANCE</u> -

This input can be either 0.0 or the actual value if available. Refer to item <u>86</u> for explanation. See Figure K5 for location.

$$P_3 = 3.19 \left[\frac{3\,(b_{p1}) + (b_{p2})}{8} \right] \frac{(\ell_p)}{(\ell_3)}$$

$$- \; 3.19 \left[\frac{3\,(76) + (76)}{8} \right] \frac{(76)}{(82a)}$$

(82a) ℓ_3 <u>LENGTH OF PERMEANCE PATH P_3</u> - ℓ_3 is the length of permeance path P_3 and must be obtained from design layout. Note: This value (ℓ_3) must appear as an input when P_2 = <u>0.0</u>

(83) P_4 <u>POLE UNDERSIDE TO POLE UNDERSIDE LEAKAGE PERMEANCE</u>

This input can be either <u>0.0</u> or the actual value if available. Refer to item 77a for explanation. See Figure K6 for location.

For 6 poles or more i.e. when (6) $\gtrsim$ 6 calculate as follows:

$$*P_4 = \frac{3.19\,(\ell_p)}{\pi} \ln \left[1 + \frac{(b_{p1}) + (b_{p2})}{(Z)} \right]$$

$$- \; \frac{3.19\,(76)}{\pi} \ln \left[1 + \frac{(76) + (76)}{(83)} \right]$$

where $z = \tau_p - \left[\frac{(b_{p1}) + (b_{p2})}{2}\right] = (41) - \left[\frac{(76) + (76)}{2}\right]$

For 4 poles i.e. when (6) = 4 calculate as follows:

$$*P_4 = \frac{3.19\,(\ell_p)}{} \; \frac{3}{2} \; \ln\left[1 + \frac{(b_{p1} + (b_{p2})}{z}\right]$$

$$= \frac{3.19\,(76)}{\pi} \cdot \frac{3}{2} \; \ln\left[1 + \frac{(76) + (76)}{83}\right]$$

(84)	P_5	<u>FIELD COIL LEAKAGE PERMEANCE</u> - This input can be either 0.0 or the actual value if available. Refer to item <u>77a</u> for explanation. See Figure F-7 for location.

$$P_5 = \frac{3.19}{(\ell_{co})} \; \frac{\pi}{4} \left[(d_{oc})^2 - (d_s)^2\right] \frac{2}{3}$$

$$= \frac{3.19}{(78)} \; \frac{\pi}{4} \left[(78)^2 - (78)^2\right] \frac{2}{3}$$

(86)	P_7	<u>STATOR TO ROTOR LEAKAGE PERMEANCE</u> - This input can be either <u>0.0</u> or the actual value if available. Refer to item 86 for explanation. See Figure F-7 for location.

$$P_7 = 2.5\,(D + d_r)$$

$$= 2.5\left[(12) + (11a)\right]$$

(87) The next set of calculations deals with the no load saturation. When the no load saturation data is required at various voltages, insert 1. on the input sheet for "No Load Sat.". The computer will then calculate the complete no load saturation curve at 80, 90, 100, 110, 120, 130, 140, '50, and 160% of rated volts. When complete saturation data is not necessary, insert 0. on the input sheet and the computer will calculate 100% volt data.

(88)	ϕ_T	TOTAL FLUX IN KILO LINES
(91)	B_t	TOOTH DENSITY in Kilo Lines/in^2
(92)	ϕ_P	FLUX PER POLE in Kilo Lines
(94)	B_c	CORE DENSITY in Kilo Lines/in^2
(95)	B_g	GAP DENSITY in Kilo Lines/in^2
(96)	F_g	AIR GAP AMPERE TURNS
(97)	F_T	STATOR TOOTH AMPERE TURNS
(98)	F_c	STATOR CORE AMPERE TURNS
(98a)	F_s	STATOR AMPERE TURNS, total
(99)	ϕ_7	STATOR TO SHAFT AND FLUX PLATE LEAKAGE FLUX -

The leakage flux from the stator to the yoke and rotor, all of which crosses the auxiliary air gaps (g_2) and (g_3)

$$\phi_7 = \left[(F_P)+(F_g)+(F_T)+(F_c)\right] (P_7) \times 10^{-3}$$

$$= \left[(104a)+(96)+(97)+(98)\right] (86) \times 10^{-3}$$

The items to follow are to be calculated for variable loads. The first set of calculations are at no load. These calculations will then be repeated for 100% load. Any variation in load would be a repeat of the 100% load calculations with the proper percent load inserted.

(100a) ϕ_ℓ **ROTOR LEAKAGE FLUX** - at no load

$$\phi_\ell = (p)\left[2(F_g) + 2(F_T) + (F_c)\right]\left[(P_1) + (P_2) + (P_3) + (P_4)\right] \times 10^{-3}$$

$$= (6)\left[2(96) + 2(97) + (98)\right]\left[(80) + (81) + (82) + (83)\right] \times 10^{-3}$$

(102a) ϕ_{PT} **TOTAL FLUX PER POLE** - at no load

$$\phi_{PT} = \phi_P + \frac{2(\phi_\ell)}{P} = (92) + \frac{2(100a)}{(6)}$$

(103a) B_P **POLE DENSITY** in Kilolines per square inch.

(104a)	F_P	<u>POLE AMPERE TURNS</u> - at no load. The ampere turns per pole required to force the flux through the pole at no-load rated voltage. The no load pole ampere turns per pole are calculated as the product of (ℓ_p) times the NI per inch at the density (B_P). Use magnetization curve submitted per Item (18) for rotor.
		$F_P = (\ell_p) \left[\text{NI/in @ density } (B_P) \right]$
		$= (76) \left[\begin{array}{l} \text{Look up on rotor magnetization curve} \\ \text{given in (18) @ density (103a)} \end{array} \right]$
(108)	ϕ_{g2}	<u>FLUX CROSSING THE AUXILIARY AIR GAP</u> - Kilolines
		$\phi_{g2} = (\phi_{PT}) \frac{(P)}{2} + (\phi_7)$
		$= (102a) \frac{(6)}{2} + (96)$
(111)	ϕ_{SH}	<u>FLUX IN SHAFT</u>
		$\phi_{SH} = (\phi_{g2}) + (\phi_5) = (108) + (118)$
(112)	A_s	<u>AREA OF SHAFT</u> in inches^2 - cross-sectional to flux
		Where $A_s = \frac{\pi}{4} (d_s)^2 = \frac{\pi}{4} (78)^2$

(113) B_{sh} FLUX DENSITY IN SHAFT

$$B_s = \frac{(\emptyset_{sh})}{(A_s)} = \frac{(111)}{(112)}$$

(114) F_{sh} AMPERE TURN DROP IN SHAFT

$$F_{sh} = \left[l_{sh}\right]\left[\text{NI/inch at density } (B_{sh})\right]$$

$$= (78) \left[\begin{array}{l}\text{Look up on shaft magnetization curve} \\ \text{given in (18) at density (113)}\end{array}\right]$$

(118) $\emptyset_5$ COIL LEAKAGE FLUX

$$\emptyset_5 = P_5) \left[(F_{g2}) + 2(F_g) + 2(F_p) + 2(F_T) + (F_c) + (F_{g3})\right] \times 10^{-3}$$

$$= (34) \left[(123) + 2(96) + 2(104a) + 2(97) + (98) + (120)\right] \times 10^{-3}$$

(119) B_{g3} AUXILIARY AIR GAP (g_3) DENSITY - Note the flux crossing air gap (g_2) is equal the flux crossing air gap (g_3)

$$B_{g3} = \frac{\emptyset_{g2}}{A_{g3}} = \frac{(108)}{(70a)}$$

(120) F_{g3} AUXILIARY AIR GAP (g_3) AMPERE TURNS

$$F_{g3} = \frac{(B_{g3})}{3.19}(g_3)(10^3) = \frac{(119)}{3.19} (59b) \times 10^3$$

(120a)	--	YOKE - No provision is made in this manual for calculating the flux densities in the section designated y_1 and y_2 in Fig. K-7, page K-14. Make sure that the underside periphery of the pole base times the thickness of the flux plate y_1 is equal to the cross-section of the pole base; or that the flux plate is equal to the pole thickness. The pole areas are assumed to be equal.
(122)	B_{g2}	AUXILIARY GAP (g_2) DENSITY $B_{g2} = \frac{\phi_{g2}}{A_{g2}} = \frac{(108)}{(70)}$
(123)	F_{g2}	AUXILIARY AIR GAP (g_2) AMPERE TURNS $F_{g2} = \frac{(B_{g2})}{3.19} (g_2) \times 10^3 = \frac{(122)}{3.19} (59a) \times 10^3$
(127)	F_{NL}	TOTAL AMPERE TURNS - at no load. The total ampere turns per pole required to produce rated voltage at no load. $F_{NL} = 2(F_g) + 2(F_T) + (F_c) + (F_{sh}) + (F_{g3}) + (F_{g2}) + 2(F_p)$ $= 2(96) + 2(97) + (98) + (114) + (120) + (123) + 2(104a)$

(127a)	I_{FNL}	FIELD CURRENT - at no load.
		$I_{FNL} = (F_{NL})/(N_F) = (127)/(146)$
(127b)	E_F	FIELD VOLTS - at no load.
(127c)	S_F	CURRENT DENSITY - at no load.
(128)	A	AMPERE CONDUCTORS per inch
(129)	X	REACTANCE FACTOR
(130)	X_ℓ	LEAKAGE REACTANCE
		$X_\ell = X\left[\lambda_i + \lambda_e + \lambda_z\right]$
		$= (129)\left[(62) + (64) + (64a)\right]$
		λ_z is explained under item (64a) and should be zero in most cases.
(131)	X_{ad}	REACTANCE - direct axis - This is the fictitious reactance due to armature reaction in the direct axis.

$$X_{ad} = \frac{.9(N_e)(I_{PH})(C_M)(K_d) \times 100}{(P)\left[(2F_g) + (F_{g2}) + (F_{g3})\right]} = \frac{.9(45)(8)(74)(43) \times 100}{(6)\left[2(96) + (123) + (120)\right]}$$

(132)	X_{aq}	<u>REACTANCE</u> - quadrature axis - This is the fictitious reactance due to armature reaction in the quadrature axis. $$X_{aq} = \frac{(C_q)(X_{ad})}{(C_m)(C_1)} = \frac{(71)(131)}{(74)(75)}$$
(133)	X_d	<u>SYNCHRONOUS REACTANCE</u> - direct axis
(134)	X_q	<u>SYNCHRONOUS REACTANCE</u>
(145)	V_r	<u>PERIPHERAL SPEED</u>

(146)	N_F	NUMBER OF FIELD TURNS TOTAL
(147)	ℓ_{tf}	MEAN LENGTH OF FIELD TURN
(148)	--	FIELD CONDUCTOR DIA OR WIDTH in inches
(149)	--	FIELD CONDUCTOR THICKNESS in inches - Set this item = 0 for round conductor
(150)	$X_f\,^{o}C$	FIELD TEMP IN ^{o}C - Input temp at which full load field loss is to be calculated.
(151)	ρ_f	RESISTIVITY of field conductor @ $20^{o}C$ in micro ohm-inches. Refer to table given in Item (51) for conversion factors.
(152)	ρ_f (hot)	RESISTIVITY of field conductor at $X_f\,^{o}C$
(153)	a_{cf}	CONDUCTOR AREA OF FIELD WINDING
(154)	R_f (cold)	COLD FIELD RESISTANCE @ $20^{o}C$ $R_f \text{ (cold)} = (\rho_f)\,\frac{(N_f)(\ell_{tf}) \times 10^{-6}}{(a_{cf})} = (151)\,\frac{(146)(147) \times 10^{-6}}{(153)}$
(155)	R_f (hot)	HOT FIELD RESISTANCE - Calculated at $X_f\,^{o}C$ (103) $R_f \text{ (hot)} = (\rho_{f \text{ hot}})\,\frac{(N_f)(\ell_{tf}) \times 10^{-6}}{(a_{cf})} = (152)\,\frac{(146)(147) \times 10^{-6}}{(153)}$

(156)	--	WEIGHT OF FIELD COPPER in lbs
		#'s of copper = $.321(N_f)(\ell_{tf})(a_{cf})$
		$= .321(146)(147)(153)$
		NOTE: Also refer to note given in item (65).
(157)	--	WEIGHT OF ROTOR IRON
(160)	X_F	THE EFFECTIVE FIELD LEAKAGE REACTANCE (X_F)

The reactance which added to the stator leakage reactance gives the transient reactance X'_{du}.

$$X_F = X_{ad}\left[1 - \frac{\frac{C_1}{C_m}}{2C_p + \frac{4}{\pi}\frac{\lambda_F}{\lambda_a}}\right]$$

$$X_F = (131)\left[1 - \frac{\frac{(71)}{(74)}}{2(73) + \frac{4}{\pi}\frac{(160)}{(160)}}\right]$$

$$\lambda_a = \frac{6.38d}{P_{ge}'} = \frac{6.38(11)}{(6)(160)}$$

$$\lambda_F = \frac{P_e}{\ell} = \frac{(160a)}{(13)}$$

Where $g'_e = (g_e)\left[\frac{2(F_g)+(F_{g2})+(F_{g3})}{2(F_g)}\right] = (69)\left[\frac{2(96)+(123)+(120)}{2(96)}\right]$

(160a)	P_e	FIELD LEAKAGE PERMEANCE

$$P_e = (p)\left[P_1 + P_2 + P_3 + P_4\right] + P_5$$
$$= (6)\left[(80) + (81) + (82) + (83)\right] + (84)$$

(160b)	P_r	ROTOR LEAKAGE PERMEANCE

$$P_r = p\left[P_1 + P_2 + P_3 + P_4\right]$$
$$= (6)\left[(80) + (81) + (82) + (83)\right]$$

(161)	L_f	FIELD SELF-INDUCTANCE

$$L_f = (N_F)^2 \times P_e \times 10^{-8} = (146)^2\,(160a) \times 10^{-8}$$

(166)	X'_{du}	UNSATURATED TRANSIENT REACTANCE
(167)	X'_d	SATURATED TRANSIENT REACTANCE
(168)	X''_d	SUBTRANSIENT REACTANCE in direct axis

$$X''_d = (X'_d) = (167)$$

(169)	X''_q	SUBTRANSIENT REACTANCE in quadrature axis

$$X''_q = X_q = (134)$$

(170)	X_2	NEGATIVE SEQUENCE REACTANCE
(172)	X_0	ZERO SEQUENCE REACTANCE
(173)	K_{xo}	
(174)	K_{x1}	
(175)	λ_{Bo}	$\lambda_{Bo} = \frac{(K_{xo})}{(K_p)^2}\left[.07(\lambda_a)\right] = \frac{(173)}{(44)^2}\left[.07(175)\right]$ Where $\lambda_a = \frac{6.38(d)}{(P)(g_e)} = \frac{6.38(11)}{6(69)}$
(176)	T'_{do}	OPEN CIRCUIT TIME CONSTANT
(177)	T_a	ARMATURE TIME CONSTANT
(178)	T'_d	TRANSIENT TIME CONSTANT
(179)	T''_{do}	SUBTRANSIENT TIME CONSTANT
(180)	F_{SC}	SHORT CIRCUIT AMPERE TURNS - The field ampere turns required to circulate rated stator current when the stator is short circuited. $F_{SC} = \frac{(X_d)}{100}\left[2(F_g) + (F_{g2}) + (F_{g3})\right]$ $= \frac{(133)}{100}\left[2(96) + (123) + (120)\right]$

(181)	SCR	<u>SHORT CIRCUIT RATIO</u>
(182)	I^2R_F	<u>FIELD I^2R</u> - at no load. The copper loss in the field winding is calculated with cold field resistance at 20°C for no load condition. Field $I^2R = (I_{FNL})^2 \ (R_{f\ cold}) = (127a)^2 \ (154)$

(183)	F & W	<u>FRICTION & WINDAGE LOSS (KW)</u> - Note: Write 0 on input sheet when computer is to calculate F & W. Insert actual value when known.

To ratio from test data, assume that F & W loss varies as the 5/2 power of the rotor diameter and as the 3/2 power of the RPM.

The formula below gives an approximate answer when test data is not available. For a more rigorous treatment use the information given in the rotor friction analysis appended to the therma analysis section (Section C, Vol. 1).

$$F\&W = 2.52 \times 10^{-6} (d_T)^{2.5} (RPM)^{1.5} (\ell_\rho)$$

$$= 2.52 \times 10^{-6} (11a)^{2.5} (7)^{1.5} \quad (76)$$

For gases or fluids other than standard air, the fluid density and viscosity must be considered. The formula given in the manual can be modified by the factors

$$\left(\frac{\rho}{.0765}\right)^{.8} \left(\frac{u}{.0435}\right)^{.2}$$

		where ρ = density - Lbs FT^{-3}
		μ = viscosity LBS FT^{-1} HR^{-1}
		.0765 = density std. air
		.0435 = viscosity std. air
(184)	W_{TNL}	STATOR TEETH LOSS - at no load.
(185)	W_c	STATOR CORE LOSS
(186)	W_{NPL}	POLE FACE LOSS - at no load.
(187)	K_1	
(188)	K_2	
(189)	K_3	
(190)	K_4	
(191)	K_5	
(192)	K_6	
(194)	I^2R	STATOR I^2R - at no load.
(195)	--	EDDY LOSS - at no load.

(196) | -- | <u>TOTAL LOSSES</u> - at no load. Sum of all losses.

$$\text{Total Losses} = (\text{Field } I^2R) + (F\&W) + (\text{Stator Teeth Loss}) + (\text{Stator Core Loss}) + (\text{Pole Face Loss})$$

$$= (182) + (183) + (184) + (185) + (186)$$

NOTE: The output sheet shows the next items to be: (Rating), (Rating + Losses), (% Losses), (% Efficiency). These items do not apply to the no load calculation since the rating is zero.

(196a) | $\phi_{\ell\ell}$ | <u>LEAKAGE FLUX PER POLE</u> at 100% load

$$\phi_{\ell\ell} = \phi_{\ell}\left\{\frac{(e_d)(F_g) + \left[1 + \cos(\theta)\right](F_T) + (F_C)}{(F_g) + (F_T) + (F_C)}\right\}$$

$$= (100a)\left\{\frac{(198)(96) + \left[1 + \cos(198a)\right](97) + (98)}{(96) + (97) + (98)}\right\}$$

(198) | e_d | Where $e_d = \cos\epsilon + \frac{(X_d)}{100}\sin\psi$

$$= \cos(198a) + \frac{(133)}{100}\sin(198b)$$

(198a)	θ	Where $\theta = \cos^{-1}\left[(\text{Power Factor})\right]$ $= \cos^{-1}\left[(9)\right]$
		Where $\Psi = \tan^{-1}\left[\dfrac{\sin(\theta) + (X_q)/(100)}{\cos(\theta)}\right]$
		$= \tan^{-1}\left[\dfrac{\sin(198a) + (124)/(100)}{\cos(198a)}\right]$
		Where $\epsilon = \Psi - \theta = (198a) - (198a)$
(207)	ϕ_{7L}	FLUX LEAKAGE FROM STATOR TO ROTOR
		$\phi_{7L} = (P_7)\left[(e_d)(F_g) + (F_{PL}) + (F_T)\left[1 + \cos(\theta)\right] + (F_c)\right] \times 10^{-3}$
		$= (86)\left[(198)(96) + (213c) + (97)\left[1 + \cos(198a)\right] + (98)\right] \times 10^{-3}$
(213)	ϕ_{PL}	FLUX PER POLE at 100% load
(213a)	ϕ_{PTL}	TOTAL FLUX PER POLE at 100% load
		$\phi_{PTL} = \phi_{PL} + \dfrac{2(\phi_{\ell\ell})}{(P)} = (213) + \dfrac{2(196a)}{(6)}$
(213b)	B_{PL}	FLUX DENSITY AT BASE OF POLE at 100% load
(213c)	F_{PL}	AMPERE TURNS PER POLE at 100% load
		$F_{PL} = (\ell_p)\left[NI/in\ @\ density\ (B_{PL})\right]$
		= (76) [Look up ampere turns/inch on rotor magnetization curve given in (18) at density (213b)]

(221)	ϕ_{g2L}	TOTAL FLUX IN AUXILIARY AIR GAP under load
		$$\phi_{g2L} = (\phi_{PTL}) \frac{(P)}{2} + (\phi_{7L})$$
		$$= (213a) \cdot \frac{(6)}{2} + (207)$$
(224)	B_{g2L}	FLUX DENSITY IN AUXILIARY AIR GAP under load
		$$B_{g2L} = \frac{\phi_{g2L}}{(A_{g2})} = \frac{(221)}{(70)}$$
(225)	F_{g2L}	AUXILIARY AIR GAP AMPERE TURN DROP under load
		$$F_{g2L} = (B_{g2L}) \frac{(g_2)}{3.19} \times 10^3 = (224) \frac{(59a)}{3.19} \times 10^3$$
(226)	ϕ_{5L}	COIL LEAKAGE FLUX UNDER LOAD
		$$\phi_{5L} = (P_5)\Big[2(e_d)(F_g) + 2(F_{PL}) + (F_{g2L}) + (F_c) + (F_{g3L}) + 2(F_T)\left[1 + \cos(\theta)\right]\Big] \times 10^{-3}$$
		$$= (84)\Big[2(198)(96) + 2(213c) + (225) + (98) + (231) + 2(97)\left[1 + \cos(198a)\right]\Big] \times 10^{-3}$$
(230)	B_{g3L}	AUXILIARY GAP (g_3) FLUX DENSITY - note the flux in air gap (g_2) is equal to flux in gap (g_3)
		$$B_{g3L} = \frac{(\phi_{g2L})}{(A_{g3})} = \frac{(221)}{(70a)}$$

(231)	F_{g3L}	AUXILIARY GAP (g_3) AMPERE TURN DROP under load
		$F_{g3L} = \frac{(B_{g3L})(g_3)}{3.19} \times 10^3 = \frac{(230)(59b)}{3.19} \times 10^3$
(231a)	ϕ_{SHL}	SHAFT FLUX
		$\phi_{SHL} = (\phi_{g2L}) + (\phi_{5L}) = (221) + (226)$
(232)	B_{SHL}	SHAFT DENSITY
		$B_{SHL} = \frac{(\phi_{SHL})}{(A_s)} = \frac{(231a)}{(112)}$
(233)	F_{SHL}	SHAFT AMPERE TURN DROP
		$F_{SHL} = (\ell_{SH}) \left[\text{NI/inch @ } (B_{SHL}) \right]$
		$= (78) \left[\text{Look upon shaft magnetization curve @ density (232)} \right]$
(236)	F_{FL}	TOTAL AMPERE TURNS under load
		$F_{FL} = (F_{SHL}) + 2(F_{PL}) + (F_{g2L}) + (F_{g3L}) + (F_c) + 2(F_g)(e_d) + 2(F_T) \left[1 + \cos(\theta)\right]$
		$= (233) + 2(213c) + (225) + (231) + (98) + 2(96)(198) + 2(97) \left[1 + \cos(198a)\right]$
(237)	I_{FFL}	FIELD AMPERES under load
		$I_{FFL} = \frac{(F_{FL})}{(N_F)} = \frac{(236)}{(146)}$
(239)	--	CURRENT DENSITY at 100% load

(238)	E_{FFL}	FIELD VOLTS at 100% load
(241)	I^2R_{FL}	FIELD I^2R at 100% load
(242)	W_{TFL}	STATOR TEETH LOSS at 100% load
(243)	W_{PFL}	POLE FACE LOSS at 100% load
(245)	I^2R_L	STATOR I^2R at 100% load
(246)	--	EDDY LOSS
(247)	--	TOTAL LOSSES at 100% load - sum of all losses at 100% load. Total Losses = (FIELD I^2R) + (F&W) + (Stator Teeth Loss) + (Stator Core Loss) + (Pole Face Loss) + (Stator I^2R) + (Eddy Loss) = (241) + (183) + (242) + (185) + (243) + (245) + (246)
(248)	--	RATING IN KW
(249)	--	RATING & LOSSES
(250)	--	% LOSSES

(251)	--	<u>% EFFICIENCY</u>

Item (196a) through (251) are 100% load calculations. These items can be recalculated for any load condition by simply inserting the values that correspond to the % load being calculated. The factor $\frac{(\%\ \text{Load})}{100}$ takes care of (I_{PH}) as it changes with load.

Note that values for F&W (183) and W_C (Stator Core Loss) (185) do not change with load, therefore, they can be calculated only once.

INPUT AUXILIARY DATA SHEET

Auxiliary information taken from the design manuals to be used in conjunction with input sheets for convenience.

A. All dimensions for lengths, widths, and diameters are to be given in inches.

B. Resistivity inputs, Items (141) and (151) are to be given in micro-ohm-inches.

The following items along with an explanation of each are tabulated here for convenience. For complete explanation of each item number, refer to design manuals.

Item No.	Explanation
(9)	Power factor to be given in per unit. For example for 90% P. F., insert .90.
(9a)	Adjustment Factor - For P.F. $<$ .95 insert 1.0 For P.F. $>$ .95 insert 1.05
(10)	Optional Load Point -- Where load data output is required at a point other than those given as standard on the input sheet. Example: For load data output at 155% load, insert 1.55.
(14)	Number of radial ducts in stator.
(15)	Width of radial ducts used in Item (14).
(18)	Magnetization curve of material used to be submitted as defined in Item (18).
(19)	Watts/Lb. to be taken from a core loss curve at the density given in Item (20) (Stator).
(20)	Density in kilolines/in^2. This value must correspord to density used to pick Item (19) usually use 77.4 KL/in^2.
(21)	Type of slot - For open slot Type A, insert 1.0. For partially open slot Type B with constant slot width, insert 2.0. For partially open slot Type C with constant tooth width, insert 3.0. For round slot Type D, insert 4.0. For additional information, refer to figure adjacent to input sheet which shows a picture of each slot.
(22)	For stator slot dimension - for dimensions that do not apply to the slot insert 0.0. Use Table below as guide for input.

Symbol	Item	Slot Type 1	2	3	4
b_o	(22)	0.0	*	*	*
b_1		0.0	0.0	*	0.0
b_2		0.0	0.0	*	0.0
b_3		0.0	0.0	*	0.0
b_s		*	*	$\wp$	*
h_o		0.0	*	*	*
h_1		*	*	*	0.0
h_2		*	0.0	0.0	0.0
h_3		*	*	0.0	0.0
h_s		*	*	*	*
h_t		0.0	*	*	0.0
h_w		0.0	*	*	0.0

* = insert actual value.

$$\wp = b_s = \frac{b_1 + b_3}{2}$$

Item No.	Explanation
(28)	Type of winding - for wye connected winding insert 1.0. for delta connected winding insert 0.0.
(29)	Type of coil - for formed wound (rect. wire), insert 1.0. for random wound (round wire) insert 0.0.
(30)	Slots spanned - Example - for slot span of 1-10, insert 9.0.
(33)	For round wire insert diameter. For rectangular wire insert wire width.
(34)	Strands per conductor in depth only.
(34a)	Total strands per conductor in depth and width.
(35)	Diameter of coil head forming pin. Insert .25 for stator O.D. $<$ 8 inches; Insert .50 for stator O.D. $>$ 8 in.

Item No.	Explanation
(37)	Use vertical height of strand for round wire, insert 0.0.
(38)	Distance between centerline of strands in depth.

Item No.	Explanation
(39)	Stator strand thickness -- use narrowest dimension of the two dimensions given for a rectangular wire. For round wire insert 0.0.
(40)	Stator slot skew in inches.
(42a)	Phase belt angle - for 60° phase belt, insert 60°. for 120° phase belt, insert 120°.
(48)	See explanation of items (71), (72), (73), (74) and (75). Same applies here.
(87)	When no load saturation output data is required at various voltages, insert 1.0. When no load saturation information is not required, insert 0.0.
(137)	Damper bar thickness -- use damper bar slot height for rectangular bar. For round bar insert 0.0.
(138)	Number of damper bars per pole.
(140)	Damper bar pitch in inches.
(148)	For round wire insert diameter. For rectangular wire insert wire width.
(149)	For rectangular wire insert wire thickness. For round wire insert 0.0.
(187)	Pole face loss factor. For rotor lamination thickness .028 in. or less, insert 1.17. For rotor lamination thickness .029 in. to .063 in. insert 1.75. For rotor lamination thickness .064 in. to .125 insert 3.5. For solid rotor insert 7.0.
(71) (72) (73) (74) (75)	If the values of these constants are available, insert the actual number. If they are not available, insert 0.0 and the computer will calculate the values and record them on the output.

TWO-COIL LUNDELL (BECKY-ROBINSON TYPE)

COMPUTER DESIGN - - - - - - - - (INPUT)

MODEL ______________ EWO ______________ DESIGN NO(1) ______________

Group	No.	Symbol	Item	Value
PARAMETERS	(2)	KVA	GENERATOR KVA	
	(3)	E	LINE VOLTS	
	(4)	E_{ph}	PHASE VOLTS	
	(5)	m	PHASES	
	(5a)	f	FREQUENCY	
	(6)	p	POLES	
	(7)	RPM	RPM	
	(8)	I_{ph}	PHASE CURRENT	
	(9)	P F	POWER FACTOR	
	(9a)	K_c	ADJ. FACTOR	
	(10)		OPTIONAL LOAD POINT	
STATOR STACK	(11)	d	STATOR I.D.	
	(12)	D	STATOR O.D.	
	(13)	ℓ	GROSS CORE LENGTH	
	(14)	n_v	NO. OF DUCTS	
	(15)	b_v	WIDTH OF DUCT	
	(16)	K_i	STACKING FACTOR (STATOR)	
	(19)	k	WATTS/LB.	
	(20)	B	DENSITY	
STATOR SLOT	(21)		TYPE OF SLOT	
	(22)	b_o	SLOT OPENING	
	(22)	b_1	SLOT WIDTH TOP	
	(22)	b_2		
	(22)	b_3		
	(22)	b_s	SLOT WIDTH	
	(22)	h_o		
	(22)	h_1		
	(22)	h_2		
	(22)	h_3		
	(22)	h_s	SLOT DEPTH	
	(22)	h_t		
	(22)	h_w		
	(23)	Q	NO. OF SLOTS	
STATOR WINDING	(28)		TYPE OF WDG.	
	(29)		TYPE OF COIL	
	(30)	n_s	CONDUCTORS/SLOT	
	(31)	y	SLOTS SPANNED	
	(32)	c	PARALLEL CIRCUITS	
	(33)		STRAND DIA. OR WIDTH	
	(34)	N_{st}	STRANDS/CONDUCTOR IN DEPTH	
	(34a)	N'_{st}	STRANDS/CONDUCTOR	
	(39)		STATOR STRAND T'KNS.	
	(35)	d_b	DIA. OF PIN	
	(36)	ℓ_{e2}	COIL EXT. STR. PORT	
	(37)	h_{st}	UNINS. STRD. HT.	
	(38)	h'_{st}	DIST. BTWN. C_L OF STD.	
	(42a)		PHASE BELT ANGLE	
	(40)	τ_{sk}	STATOR SLOT SKEW	
	(50)	X °C	STATOR TEMP °C	
	(51)	ρ_s	RESISTIVITY STA. COND. @ 20 °C	
AIR GAP	(59b)		TYPE OF GAP g3	
	(59)	g	MAIN AIR GAP	
	(59a)	g_g	AUX GAP	
	(59f)	g_{3E}	EFFECTIVE g3	

Value	Item	No.	Symbol	Group
	FUND/MAX OF FIELD FLUX	(71)	C_1	CONSTANTS
	WINDING CONSTANT	(72)	C_w	
	POLE CONSTANT	(73)	C_p	
	END EXTENSION ONE TURN	(48)	L_E	
	DEMAGNETIZATION FACTOR	(74)	C_m	
	CROSS MAGNETIZING FACTOR	(75)	C_q	
	POLE EMBRACE	(77)	α	
	WIDTH OF NORTH POLE (END)	(76)	$b_{np(end)}$	POLE
	WIDTH OF SOUTH POLE (END)	(76)	$b_{sp(end)}$	
	WIDTH OF NORTH POLE (MID)	(76)	$b_{np(mid)}$	
	WIDTH OF SOUTH POLE (MID)	(76)	$b_{sp(mid)}$	
	LENGTH OF NORTH POLE	(76)	ℓ_{np}	
	LENGTH OF SOUTH POLE	(76)	ℓ_{sp}	
	ROTOR DIAMETER	(11a)	d_r	
	HEIGHT OF NORTH POLE	(78)	h_{np}	
	POLE FACE LOSS FACTOR	(187)	(K_1)	
	WIDTH OF SLOT OPENING	(135)	b_{bo}	DAMPER BAR
	HEIGHT OF SLOT OPENING	(135)	h_{bo}	
	DAMPER BAR DIA. OR WIDTH	(136)	( )	
	RECTANGULAR BAR THICKNESS	(137)	h_{bl}	
	RECTANGULAR SLOT WIDTH	(135)	b_{bl}	
	NO. OF DAMPER BARS/POLE	(138)	n_b	
	DAMPER BAR LENGTH	(139)	ℓ_b	
	DAMPER BAR PITCH	(140)	τ_b	
	RESISTIVITY OF DAMP. BAR @ 20°	(141)	ρ_D	
	DAMPER BAR TEMP °C	(142)	X °C	
	DAMPER BAR END RING MEAN DIA.	(170)	d_{dr}	
	DAMPER BAR END RING AREA	(170)	a_{dr}	
	NO. OF FIELD TURNS/COIL	(146)	N_F	FIELD
	MEAN LENGTH OF FLD. TURN	(147)	ℓ_{tF}	
	FLD. COND. DIA. OR WIDTH	(148)		
	FLD. COND. THICKNESS	(149)		
	FLD. TEMP IN °C	(150)	X_f °C	
	RESISTIVITY OF FIELD COND @ 20°	(151)	ρ_f	
	NO LOAD SAT.	(87)		
	FRICTION & WINDAGE	(183)	(F&W)	

STATOR SLOT	POLE
DAMPER SLOT	REMARKS

DESIGNER ______________ DATE ______________

PG. 1 OF 2

REV. A

TWO-COIL LUNDELL (BECKY-ROBINSON TYPE)

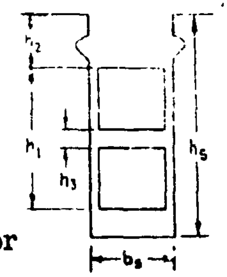
COMPUTER DESIGN - - - - - - - (INPUT)

MODEL ______________________ EWO ____________ DESIGN NO(1) ______________________

PERMEANCE	(80)	P_1	PERM OF LEAKAGE PATH 1	
	(81)	P_2	PERM OF LEAKAGE PATH 2	
	(82)	P_3	PERM OF LEAKAGE PATH 3	
	(83)	P_4	PERM OF LEAKAGE PATH 4	
	(84)	P_5	PERM OF LEAKAGE PATH 5	
	(85)	P_6	PERM OF LEAKAGE PATH 6	
	(86)	P_7	PERM OF LEAKAGE PATH 7	
	(80a)	ℓ_1	LENGTH OF LEAKAGE PATH 1	
	(81a)	ℓ_2	LENGTH OF LEAKAGE PATH 2	
	(85)	ℓ_6	LENGTH OF LEAKAGE PATH 6	
	(84)	ℓ_c	LENGTH OF LEAKAGE ACROSS COIL	
ROTOR DIMENSIONS	(73)	d_{ir}	INSIDE DIA OF ROTOR TUBE	
	(78)	d_Q	INSIDE DIA OF HOLLOW SHAFT	
	(78)	h_y	HEIGHT OF COIL YOKE	
	(78)	ℓ_y	LENGTH OF COIL YOKE	
	(78)	ℓ_{sk}	LENGTH OF ROTOR SKIRT	
	(78)	ℓ_{y4}	EFFECTIVE LENGTH OF SHAFT	
	(78)	ℓ_{g2}	HORIZONTAL LENGTH OF GAP g2	
	(78)	T_{sp}	THICKNESS OF SOUTH POLE	
	(78)	T_{sk}	THICKNESS OF ROTOR SKIRT	
GAP g3 DIMENSIONS	(78)	d_{to}	TAPERED GAP DIMENSIONS	
	(78)	d_{t1}		
	(78)	d_{s1}		
	(78)	d_{s2}		
	(78)	d_{s3}	STEPPED GAP DIMENSIONS	
	(78)	d_{s4}		
	(78)	d_{s5}		
	(78)	ℓ_{s1}		
	(78)	ℓ_{s2}		
	(78)	ℓ_{s3}	STEPPED GAP HORIZONTAL LENGTHS	
	(78)	ℓ_{s4}		
	(78)	ℓ_{s5}		
	(78)	d_{es}	EFFECTIVE SHAFT O.D.	
	(243)	W_{PHR}	POLE FACE HARMONIC LOSS	
	(244)	W_{DHR}	DAMPER BAR HARMONIC LOSS	
	(157)		WEIGHT OF ROTOR IRON	
MATERIAL	(18)		STATOR LAM. MTR'L	
	(18)		SOUTH POLE, TUBE & SKIRT	
	(18)		NORTH POLE, SPIDER & SHAFT	
	(18)		COIL YOKE	

L-02

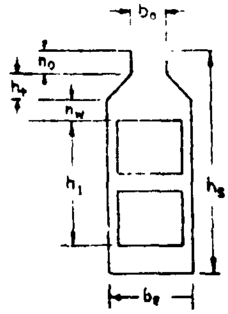
(a) Open Slots



TYPE 1

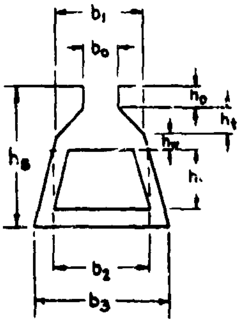
(Type 5 is an open slot with 1 conductor per slot)

(b) Constant Slot Width



TYPE 2

(c) Constant Tooth Width

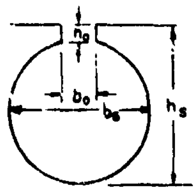


TYPE 3

b_s for type 3 is

$$b_s = \left(\frac{b_2 + b_3}{2}\right)$$

(d) Round Slots



TYPE 4

TWO-COIL LUNDELL (BECKY-ROBINSON TYPE)

SUMMARY OF DESIGN CALCULATIONS - - - - - - - (OUTPUT)

MODEL ______________________ EWO ________ DESIGN NO. ____________________

STATOR	(17)	(ℓ_s)	SOLID CORE LENGTH			CARTER COEFFICIENT	(67)	(K_s)
	(24)	(h_c)	DEPTH BELOW SLOT			EFFECTIVE AIR GAP	(69)	(g_e)
	(26)	(τ_s)	SLOT PITCH			FUND/MAX OF FIELD FLUX	(71)	(C_1)
	(27)	(τ_s 1/3)	SLOT PITCH 1/3 DIST. UP			WINDING CONST.	(72)	(C_w)
	(42)	(K_{sk})	SKEW FACTOR			POLE CONST.	(73)	(C_p)
	(43)	(K_d)	DIST. FACTOR			END. EXT. ONE TURN	(48)	(L_E)
	(44)	(K_p)	PITCH FACTOR			DEMAGNETIZING FACTOR	(74)	(C_M)
	(45)	(n_e)	EFF. CONDUCTORS			CROSS MAGNETIZING FACTOR	(75)	(C_q)
	(46)	(a_c)	COND. AREA			AMP COND/IN	(128)	(A)
	(47)	(S_a)	CURRENT DENSITY (STA.)			REACTANCE FACTOR	(129)	(X)
	(49)	(ℓ_t)	1/2 MEAN TURN LENGTH			LEAKAGE REACTANCE	(130)	(X_ℓ)
	(53)	(R_{ph})	COLD STA. RES. @ 20° C			REACTANCE OF	(131)	(X_{ad})
	(54)	(R_{ph})	HOT STA. RES.			ARMATURE REACTION	(132)	(X_{aq})
	(55)	(EF_{top})	EDDY FACTOR TOP			SYN REACT DIRECT AXIS	(133)	(X_d)
	(56)	(EF_{bot})	EDDY FACTOR BOT			SYN REACT QUAD AXIS	(134)	(X_q)
	(62)	(λ_1)	STATOR COND. PERM.			FIELD LEAKAGE REACT	(160)	(X'_f)
	(64)	(λ_e)	END PERM.			FIELD SELF INDUCTANCE	(161)	(L_f)
	(65)	( )	WT. OF STA. COPPER			DAMPER	(163)	(X_{Dd})
	(66)	( )	WT. OF STA. IRON			LEAKAGE REACTANCES	(165)	(X_{Dq})
	(41)	(τ_p)	POLE PITCH			UNSAT. TRANS. REACT	(166)	(X'_{du})
	(157)	(-)	WT. OF ROTOR IRON			SAT. TRANS. REACT	(167)	(X'_d)
	(145)	(V_r)	PERIPHERAL SPEED			SUB. TRANSREACT DIRECT AX.	(168)	(X''_d)
FIELD	(153)	(a_{cf})	FLD COND. AREA			SUB. TRANSREACT QUAD AX.	(169)	(X''_q)
	(154)	(R_f)	COLD FLD RES. @ 20 ° C			NEG. SEQUENCE REACT	(170)	(X_2)
	(155)	(R_f)	HOT FLD RES.			ZERO SEQUENCE REACT	(172)	(X_0)
	(156)	(-)	WT. OF FLD. COPPER			TOTAL FLUX	(90)	(ϕ_T)
TIME CONST.	(176)	(T'_{do})	OPEN CIR. TIME CONST.			FLUX PER POLE	(93)	(ϕ_p)
	(177)	(T_a)	ARM TIME CONST.			GAP DENSITY (MAIN)	(95)	(B'_g)
	(178)	(T'_d)	TRANS TIME CONST.			TOOTH DENSITY	(91)	(B'_t)
	(179)	(T''_d)	SUB TRANS TIME CONST.			CORE DENSITY	(94)	(B'_c)
PERMEANCE	(80)	(P_1)	PERM OF LEAKAGE PATH 1			TOOTH AMPERE TURNS	(97)	(F'_t)
	(81)	(P_2)	PERM OF LEAKAGE PATH 2			CORE AMPERE TURNS	(98)	(F'_c)
	(82)	(P_3)	PERM OF LEAKAGE PATH 3			GAP AMPERE TURNS (MAIN)	(96)	(F'_g)
	(83)	(P_4)	PERM OF LEAKAGE PATH 4			SHORT CIR NI	(180)	(FSC)
	(84)	(P_5)	PERM OF LEAKAGE PATH 5			SHORT CIR RATIO	(181)	(SCR)
	(85)	(P_6)	PERM OF LEAKAGE PATH 6					
	(86)	(P_7)	PERM OF LEAKAGE PATH 7					

PERCENT LOAD		0		100	150	200	OPTIONAL
VARIABLE LOAD	(B_{np}) (116) N.P. DENSITY		(B_{npfl}) (234)				
	(B_{sp}) (105) S.P. DENSITY		(B_{spfl}) (215)				
	(B_{y2}) (125) COIL YOKE DENSITY		(B_{y2fl}) (228)				
	(B_{y4}) (113) SHAFT DENSITY		(B_{y4fl}) (232)				
	(B_{g3}) (119) AUX. GAP(g_3)DENSITY		(B_{g3fl}) (230)				
	(B_{g2}) (122) AUX. GAP(g_2)DENSITY		(B_{g2fl}) (224)				
	(F_{nl}) (127) TOTAL NI		(F_{fl}) (236)				
	(I_f) (127a) FIELD AMPERES		(I_{ffl}) (237)				
	(S_f) (127c) CUR. DEN. FLD.		(S_{fl}) (239)				
	(E_{nl}) (127b) FIELD VOLTS		(E_{fl}) (238)				
	(W_c) (185) STA CORE LOSS		(W_c) (185)				
	(W_{tnl}) (184) STA TOOTH LOSS		(W_{tfl}) (242)				
	(W_{dnl}) (193) DAMPER LOSS		(W_{dfl}) (244)				
	(I^2R_a) (194) STATOR CU LOSS		(I^2R_a) (245)				
	(-) (195) EDDY LOSS		(-) (246)				
	(W_{pnl}) (186) POLE FACE LOSS		(W_{pfl}) (243)				
	(I^2R_f) (182) FIELD COIL LOSS		(I^2R_f) (241)				
	(F&W) (183) F&W LOSS		(F&W) (183)				
	(-) (196) TOTAL LOSSES		(-) (247)				
	(-) (-) PERCENT EFF.		(-) (251)				

L-04

DESIGNER ______________________ DATE ______________ REV. A

TWO-COIL LUNDELL (BECKY-ROBINSON TYPE)

NO LOAD SATURATION OUTPUT SHEET

ITEMS → / VOLTS	(3) (E) VOLTS	(95) B'_g DENSITY MAIN GAP	(122) B_{g2} DENSITY g2	(119) B_{g3} DENSITY g3	(94) B'_c DENSITY STATOR CORE	(91) B'_T DENSITY STATOR TOOTH
	(125) B_{y2} COIL YOKE	(105) B_{SP} DENSITY S. P.	(116) B_{NP} DENSITY N. P.	(113) B_{y4} SHAFT DENSITY	(93) ϕ'_P FLUX PER POLE	(127) F_{NL} TOTAL NI
80%						
90%						
100%						
110%						
120%						
130%						
140%						
150%						
160%						

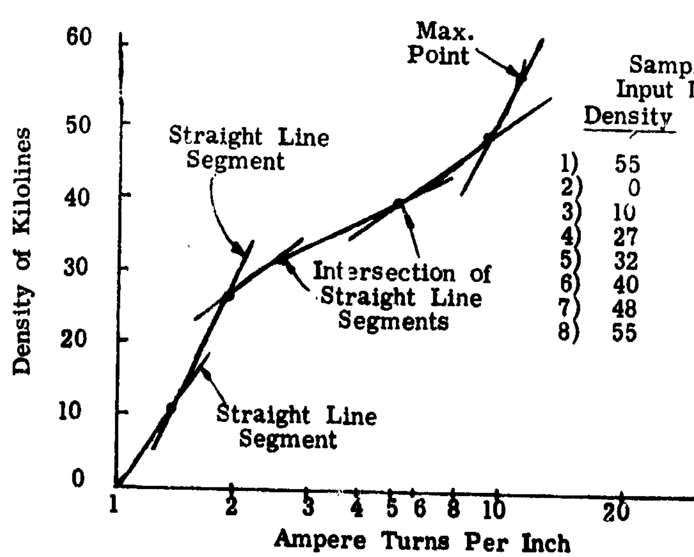
TWO-COIL LUNDELL (BECKEY-ROBINSON TYPE)
COMPUTER DESIGN MANUAL

(1)	--	DESIGN NUMBER
(2)	KVA	GENERATOR KVA
(3)	E	LINE VOLTS
(4)	E_{PH}	PHASE VOLTS
(5)	m	PHASES
(5a)	f	FREQUENCY
(6)	P	POLES
(7)	RPM	SPEED
(8)	I_{PH}	PHASE CURRENT
(9)	P. F.	POWER FACTOR
(9a)	K_c	ADJUSTMENT FACTOR
(10)	--	LOAD POINTS
(11)	d	STATOR PUNCHING I.D.
(11a)	d_r	ROTOR O.D.
(12)	D	PUNCHING O.D.
(13)	ℓ	GROSS STATOR CORE LENGTH
(14)	n_v	RADIAL DUCTS
(15)	b_v	RADIAL DUCT WIDTH
(16)	K_i	STACKING FACTOR
(17)	ℓ_s	SOLID CORE LENGTH

(18) **MATERIAL** - This input is used in selecting the proper magnetization curves for stator; tube, south pole and skirt; yoke; north pole, spider and shaft; when different materials are used. Separate spaces are provided on the input sheet for each section mentioned above. Where curves are available on card decks, used the proper identifying code. Where card decks are not available submit data in the following manner:

The magnetization curve must be available on semi-log paper. Typical curves are shown in this manual on Curves F15 and F16. Draw straight line segments through the curve starting with zero density. Record the coordinates of the points where the straight line segments intersect. Submit these coordinates as input data for the magnetization curve. The maximum density point must be submitted first.

Refer to Figure below for complete sample



Sample Input Data

	Density	NI
1)	55	Max.
2)	0	0
3)	10	1.5
4)	27	1.9
5)	32	2.5
6)	40	4.9
7)	48	9.0
8)	55	12.0

(19)	k	WATTS/LB
(20)	B	DENSITY
(21)		TYPE OF STATOR SLOT
(22)		ALL SLOT DIMENSIONS
(23)	Q	STATOR SLOTS
(24)	h_c	DEPTH BELOW SLOTS
(25)	q	SLOTS PER POLE PER PHASE
(26)	τ_s	STATOR SLOT PITCH
(27)	$\tau_s 1/3$	STATOR SLOT PITCH
(28)	--	TYPE OF WINDING
(29)	--	TYPE OF COIL
(30)	n_s	CONDUCTORS PER SLOT
(31)	Y	THROW
(31a)		PER UNIT OF POLE PITCH SPANNED
(32)	C	PARALLEL PATHS
(33)	--	STRAND DIA. OR WIDTH
(34)	N_{ST}	NUMBER OF STRANDS PER CONDUCTOR IN DEPTH
(34a)	N'_{ST}	NUMBER OF STRANDS PER CONDUCTOR
(35)	d_b	DIAMETER OF BENDER PIN
(36)	ℓ_{e2}	COIL EXTENSION BEYOND CORE
(37)	h_{ST}	HEIGHT OF UNINSULATED STRAND
(38)	h'_{ST}	DISTANCE BETWEEN CENTERLINES OF STRANDS IN DEPTH

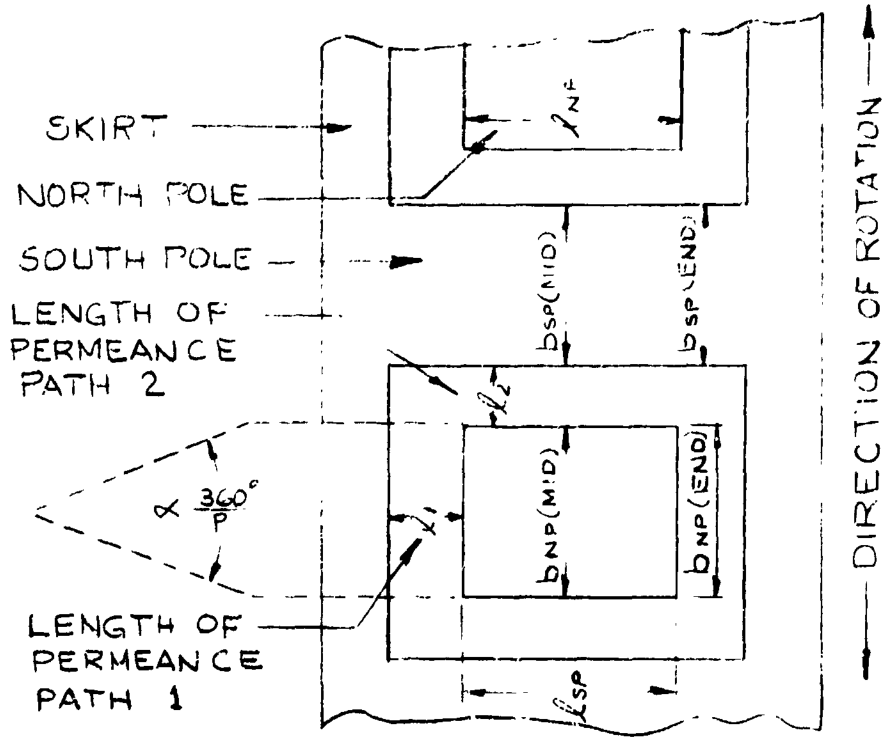
(39)	--	STATOR COIL STRAND THICKNESS
(40)	τ_{SK}	SKEW
(41)	τ_P	POLE PITCH
(42)	K_{SK}	SKEW FACTOR
(42a)		PHASE BELT ANGLE
(43)	K_d	DISTRIBUTION FACTOR
(44)	K_p	PITCH FACTOR
(45)	n_e	TOTAL EFFECTIVE CONDUCTORS
(46)	a_c	CONDUCTOR AREA OF STATOR WINDING
(47)	S_S	CURRENT DENSITY
(48)	L_E	END EXTENSION LENGTH
(49)	ℓ_t	1/2 MEAN TURN
(50)	$X_s\,^oC$	STATOR TEMP ^oC
(51)	ρ_s	RESISTIVITY OF STATOR WINDING
(52)	$\rho_{s\,(hot)}$	RESISTIVITY OF STATOR WINDING
(53)	R_{SPH} (cold)	STATOR RESISTANCE/PHASE
(54)	R_{SPH} (hot)	STATOR RESISTANCE/PHASE
(55)	EF (top)	EDDY FACTOR TOP
(56)	EF (bot)	EDDY FACTOR BOTTOM

(57)	b_{tm}	STATOR TOOTH WIDTH
(57a)	$b_{t\,1/3}$	STATOR TOOTH WIDTH
(58)	b_t	TOOTH WIDTH AT STATOR I.D. IN INCHES
(59)	g	MAIN AIR GAP IN INCHES
(59a)	g_2	AUXILIARY AIR GAP in inches. Refer to Figure 3
(59b)		TYPE OF GAP g_3. Refer to Figure 4 For stepped gap use 1. on input sheet. For tapered gap use 2. on input sheet.
(59c)	g_3	AIR GAP (g_3) in inches. Refer to Figure 4 When (59b) = 2. then $(g_3) = (g_{3e})$ (59c) = (59f) When (59b) = 1. go on to (59d)
(59d)	g_{3-1}	AIR GAP g_{3-1} in inches. Refer to Figure 4
(59e)	g_{3-2}	AIR GAP g_{3-2} in inches. Refer to Figure 4
(59f)	g_{3e}	EFFECTIVE AIR GAP LENGTH TO BE SPECIFIED ON INPUT SHEET When (59b) = 2. then $g_{3e} = g_3$ or (59f) = (59c) When (59d) = (59e), then g_{3E} = (59d) When (59d) $\neq$ (59e), then $g_{3E} = \frac{(59d) + (59e)}{2}$
(60)	C_X	REDUCTION FACTOR
(61)	K_X	FACTOR TO ACCOUNT FOR DIFFERENCE in phase current in coil sides in same slot.
(62)	λ_i	CONDUCTOR PERMEANCE
(63)	K_E	LEAKAGE REACTIVE FACTOR
(64)	λ_E	END WINDING PERMEANCE

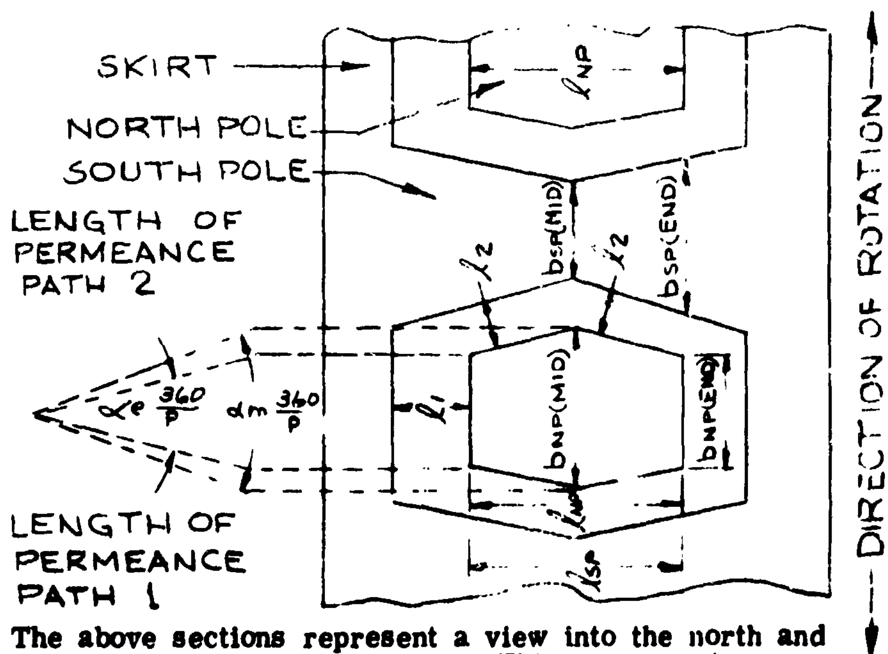
(65)	--	WEIGHT OF COPPER
(66)	--	WEIGHT OF STATOR IRON
(67)	K_s	CARTER COEFFICIENT
(68)	A_g	MAIN AIR GAP AREA
(69)	g_e	EFFECTIVE AIR GAP
(70)	A_{g2}	AUXILIARY AIR GAP (g_2) AREA $= \pi \left[(d_{ir}) + (g_2)\right] \; (\ell_{g2})$ $= \pi \left[(78) + (59a)\right] \; (78)$
(70a)	A_{g3}	AUXILIARY AIR GAP (g_3) AREA When (59b) = 1.0 calculate as follows: $A_{g3} = \pi \left\{(d_{s1})(\ell_{s1}) + (d_{s2})(\ell_{s2}) + (d_{s3})(\ell_{s3}) + (d_{s4})(\ell_{s4}) + (d_{s5})(\ell_{s5})\right\} + \pi \left\{\frac{(d_{os})^2 - (d_{s1})^2}{4}\right\}$ = All dimensions located at item (78) NOTE: Number of steps limited to 5 in this program. When (59b) = 2.0 calculate as follows: $A_{g3} = \frac{\pi}{2}\left[(d_{to}) + (d_{t1})\right] \sqrt{4(\ell_{y4})^2 + \left[(d_{to}) - (d_{t1})\right]^2}$ $A_{g3} = \frac{\pi}{2}\left[(78) + (78)\right] \sqrt{4(78)^2 + \left[(78) - (78)\right]^2}$

(71)	C_1	THE RATIO OF MAXIMUM FUNDAMENTAL of the field form to the actual maximum of the field form.
(72)	C_W	WINDING CONSTANT
(73)	C_p	POLE CONSTANT
(74)	C_M	DEMAGNETIZING FACTOR
(75)	C_q	CROSS MAGNETIZING FACTOR
(75a)	--	TYPE OF POLE - This computer program is presently set up to handle two types of pole shapes: 1) A rectangular or square type of pole. 2) A hexagonal type. Refer to Figure L-2

Type 1 (Rectangular or Square Pole)



Type 2 (Hexagonal Pole)



The above sections represent a view into the north and south pole from main air gap. This program is presently set up to handle only two types of pole shapes: 1) Rectangular or square, 2) Hexagonal.

Figure L-2

(76)	--	<u>POLE DIMENSION LOCATIONS</u> per Figure L-2 All dimensions given in inches. $b_{sp}(end)$ - Width of south pole at end of stator stack. $b_{sp}(mid)$ - Width of south pole at middle of south pole. $b_{np}(end)$ - Width of north pole at end of north pole. $b_{np}(mid)$ - Width of north pole at middle of north pole. ℓ_{sp} - Length of south pole. ℓ_{np} - Length of north pole.
(77)	α	<u>POLE EMBRACE</u> - This value must be recorded on the input sheet. When $b_{np}(end) = b_{np}(mid)$ $$\alpha = \frac{[b_{np}(end)]}{(\tau_p)} = \frac{(76)}{(41)}$$ When $b_{np}(end) \neq b_{np}(mid)$ $$\alpha = \frac{(\alpha_e) + (\alpha_m)}{2} = \frac{(77) + (77)}{2}$$ Where $\alpha_e = \frac{[b_{np}(end)]}{(\tau_p)} = \frac{(76)}{(41)}$ $$\alpha_m = \frac{[b_{np}(mid)]}{(\tau_p)} = \frac{(76)}{(41)}$$
(77a)		The next eleven (11) items deal with the calculation of rotor and stator leakage permeance. A number of illustrations are included to help identify and locate the

actual path. This computer program is set up to handle the permeance calculations two ways:

1) P_1 through P_7 can be calculated by computer. For this program insert <u>0.</u> on input sheet.

2) P_1 through P_7 can be calculated by designer. For this case insert actual calculated value on input sheet.

Permeance calculations P_1 through P_7 are all based on the equation

$$P = \frac{\mu\,(\text{area})}{\ell}$$

Where μ = 3.19

Area ℓ = cross sectional area perpendicular to

= length of path

(78) <u>ROTOR DIMENSION LOCATIONS</u> per Figure below

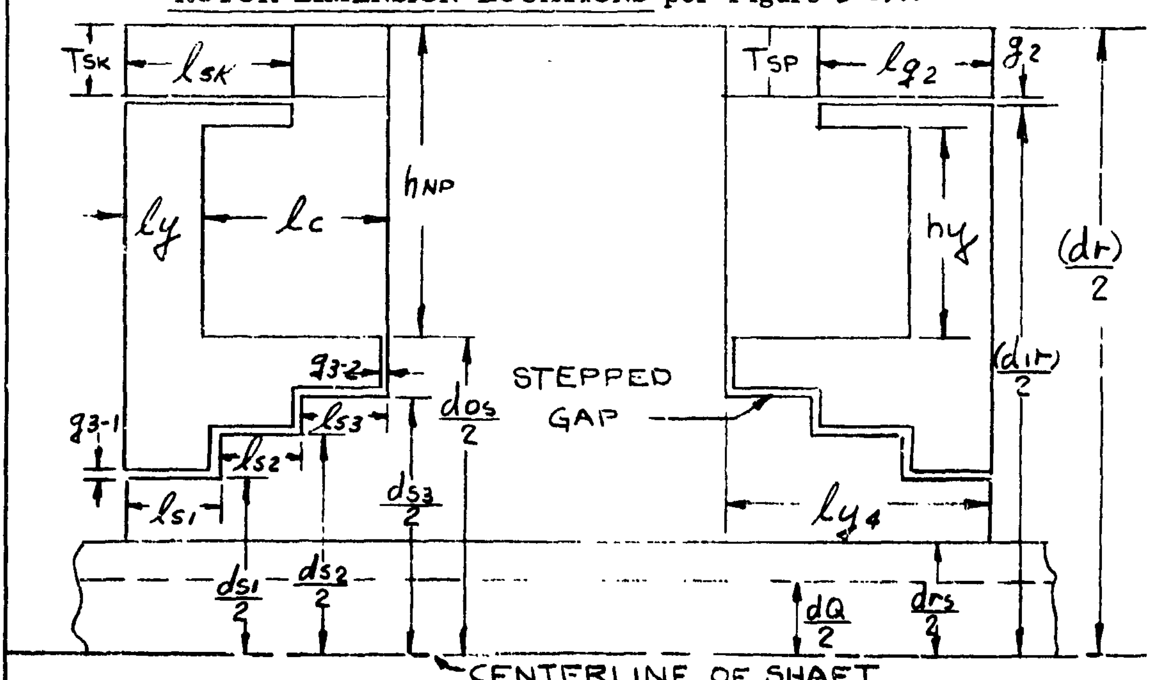


Figure L-3

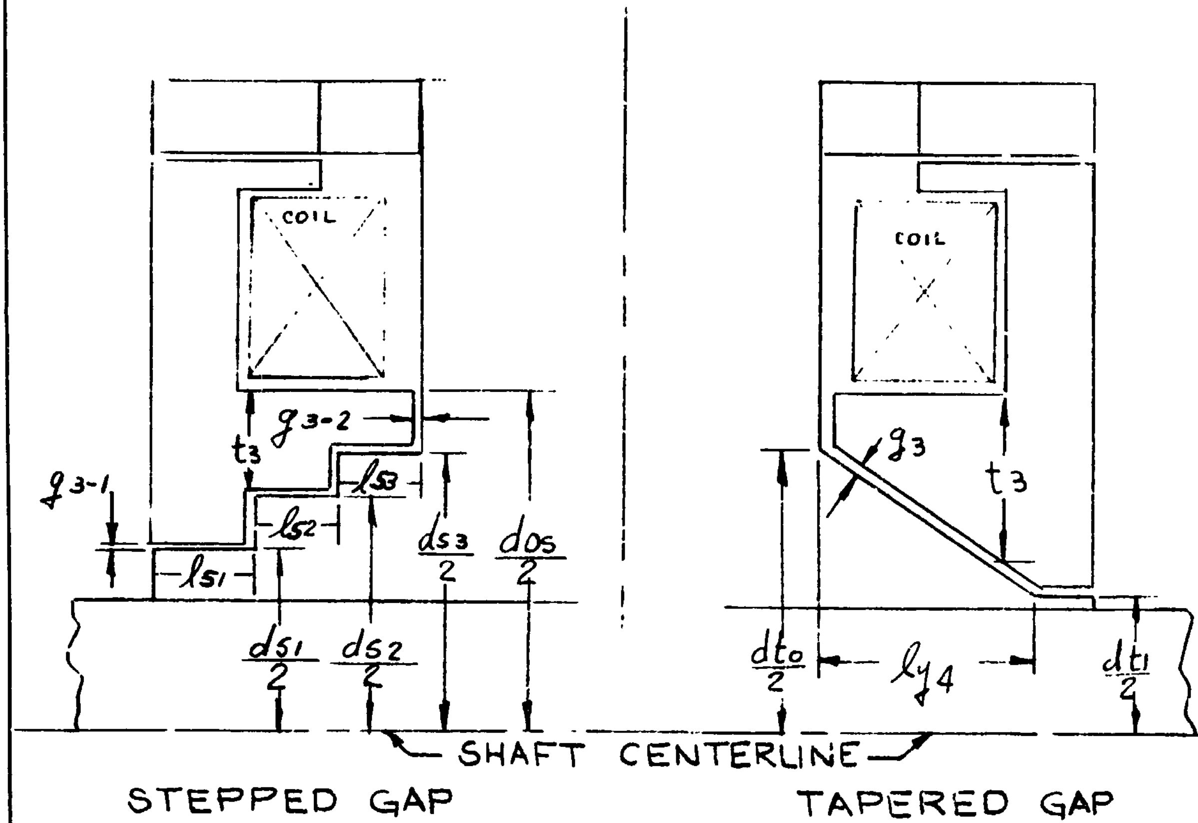


Figure L-4

(78)

$\left.\begin{array}{l} d_{s1} \\ d_{s2} \\ d_{s3} \\ d_{s4} \\ d_{s5} \\ d_{os} \end{array}\right\}$ Diameters of steps in stepped gap g_3. Computer program is set up to handle a maximum of 5 steps. Where the dimensions do not apply, insert 0.0 on input sheet.

$\left.\begin{array}{l} \ell_{s1} \\ \ell_{s2} \\ \ell_{s3} \\ \ell_{s4} \\ \ell_{s5} \end{array}\right\}$ Horizontal length of stepped gap g_3. Computer program is set up to handle a maximum of 5 steps.

(78) (CONT'D)

d_{ir} = inside diameter of tube.

d_Q = inside diameter of hollow shaft.

d_{to} For tapered gap only. Insert 0.0 on input sheet

d_{tl} when stepped gap is used.

h_{np} = Height of north pole.

h_y = Height of yoke.

ℓ_y = Length of yoke.

ℓ_{y4} = Effective length of shaft - the portion carrying flux.

ℓ_{g2} = Horizontal length of g_2.

ℓ_{sk} - Length of rotor skirt.

T_{sp} = Thickness of south pole.

T_{sk} = Thickness of rotor skirt.

All dimensions given in inches.

All dimensions listed above that apply should be filled out on input sheet. Where the dimensions do not apply, insert <u>0.0</u> on input sheet.

(79) a_{np} <u>NORTH POLE AREA</u> - The effective cross-sectional area of the north pole.

When $b_{np}(end) = b_{np}(mid)$

$$a_{np} = (\ell_{np})\left[(b_{np}(end)\right]$$
$$= (76)\ (76)$$

When $b_{np}(end) \neq b_{np}(mid)$

$$a_{np} = \frac{(\ell_{np})}{2}\left[(b_{np}(end) + (b_{np}(mid)\right]$$
$$= \frac{(76)}{2}\left[(76) + (76)\right]$$

When radially tapered poles are used, use the dimensions at the base of the pole to calculate the area.

(79a)	a_{sp}	**SOUTH POLE AREA** - The effective cross-sectional area of south pole. Cross-sectional to the path of flux at the point in line with edge of stator stack. $a_{sp} = (b_{sp}(end))(T_{sp})$ $= (76)\ (78)$
(79b)	a_{sk}	**AREA OF SKIRT** - At entry edge of auxiliary air gap g_2 in inches^2. $a_{sk} = \pi\left[(d_r) - (T_{sk})\right](T_{sk})$ $= \pi\left[(11a) - (78)\right](78)$

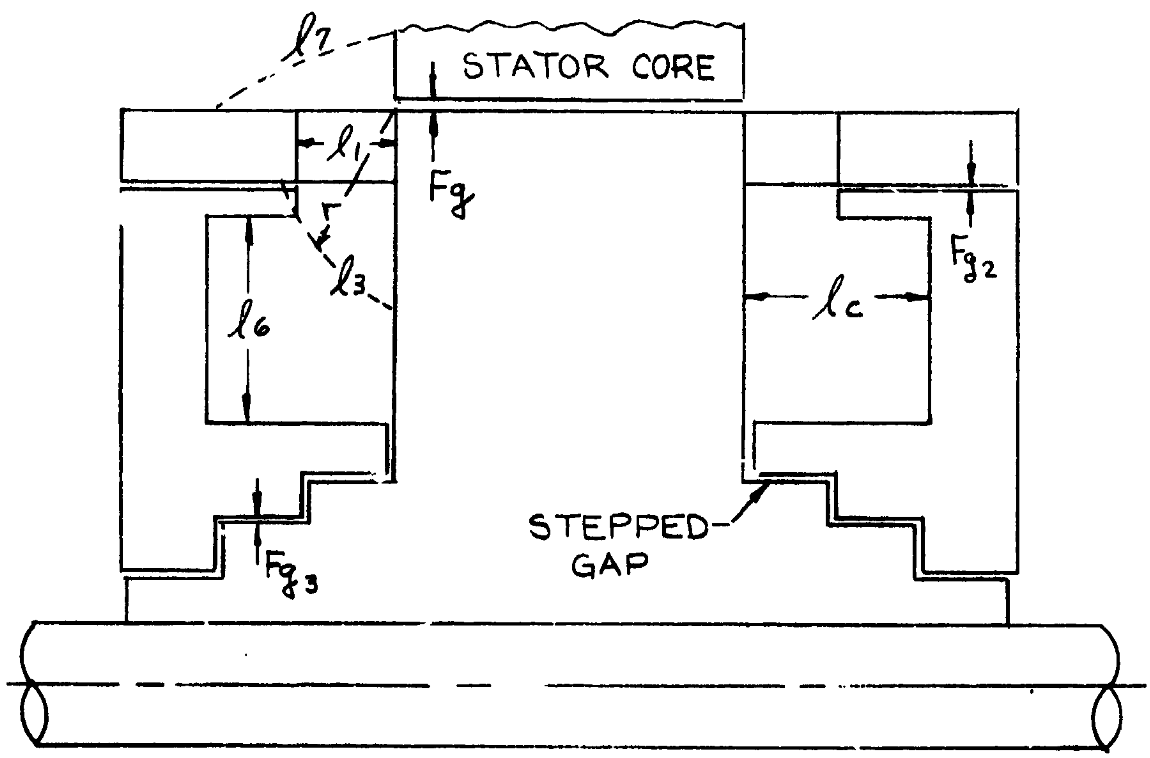


Figure L-5

(80)	P_1	POLE HEAD END LEAKAGE PERMEANCE - This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure L2 for location.

$$P_1 = 3.19 \frac{\left[(b_{np}(end)) + (\ell_2)\right]\left[(T_{sp})\ (p)\right]}{(\ell_1)}$$

$$= 3.19 \frac{\left[(76) + (81a)\right]\left[(78)\ (6)\right]}{(80a)}$$

(80a)	ℓ_1	Where ℓ_1 = length of leakage path P_1 and must be specified on input sheet. Refer to Figure L2 for location.
(81)	P_2	POLE HEAD SIDE LEAKAGE PERMEANCE - Refer to Figure L2

This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation.

When $b_{np}(end) = b_{np}(mid)$

$$P_2 = 3.19 \frac{\left[(\ell_{np}) + (\ell_1)\right]\ (T_{sp})(P)}{(\ell_2)}$$

$$P_2 = 3.19 \frac{\left[(76) + (80a)\right]\ (78)\ (6)}{(81a)}$$

When $b_{np}(end) \neq b_{np}(mid)$

$$P_2 = 6.28 \frac{\left[\frac{1}{2}\sqrt{\left[(b_{np}(mid)) - (b_{np}(end)\right]^2 + (\ell_{np})^2} + \frac{\ell_1}{2}\right](T_{sp})(P)}{(\ell_2)}$$

$$6.28 \frac{\left[\frac{1}{2}\sqrt{\left[(76) - (76)\right]^2 + (76)^2} + \frac{(80a)}{2}\right](78)(6)}{(81a)}$$

(81a)	ℓ_2	LENGTH OF LEAKAGE PATH P_2 and must be specified on input sheet. Refer to Figure L2 for location.
(82)	P_3	POLE BODY END LEAKAGE PERMEANCE - Refer to Figure L5

This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation.

$$P_3 = 3.19 \frac{\left[(b_{np}(end)\right]\left[(h_{np}) - (T_{sp})\right](P)}{\ell_3}$$

$$= 3.19 \frac{\left[(76)\right]\left[(78) - (78)\right](6)}{(82a)}$$

(82a)	ℓ_3	LENGTH OF PERMEANCE PATH P_3

$$= \left[(d_r) - (d_{os})\right]\frac{\pi}{8} - (T_{sp})$$

$$= \left[(11a) - (78)\right]\frac{\pi}{8} - (78)$$

(83)	P_4	POLE BODY SIDE LEAKAGE PERMEANCE - This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. This calculation varies with the number of poles. The four-pole calculation differs from the [illegible]-pole calculation but the 6, 8, 10 and 12 pole [illegible]ations are the same. Refer to Figures L7, L[illegible] 9

When (6) = 4 and $b_{np}(end) = b_{np}(mid)$

$$P_4 = 3.19 \frac{\left[\frac{(d_r)}{2} - (T_{sp})\right]\left[(\ell_{np}) + (\ell_1)\right](P)}{(\ell_4)}$$

$$= 3.19 \frac{\left[\frac{(11a)}{2} - (78)\right]\left[(76) + (80a)\right](6)}{(83)}$$

Where $\ell_4 = \frac{(d_r) - (d_{os})}{2} - (T_{sp})$

$$= \frac{(11a) - (78)}{2} - (78)$$

When (6) = 4 and $b_{np}(end) \neq b_{np}(mid)$

$$P_4 = 3.19 \frac{\left[\frac{(d_r)}{2} - (T_{sp})\right]\left[\frac{1}{4}\sqrt{\left[(b_{np}(mid)-(b_{np}(end)\right]^2+(\ell_{np})^2+\frac{(\ell_1)}{2}}\right]2(P)}{(\ell_4)}$$

$$= 3.19 \frac{\left[\frac{(11a)}{2} - (78)\right]\left[\frac{1}{4}\sqrt{\left[(76) - (76)\right]^2 + (76)^2 + \frac{(80a)}{2}}\right]2(6)}{(83)}$$

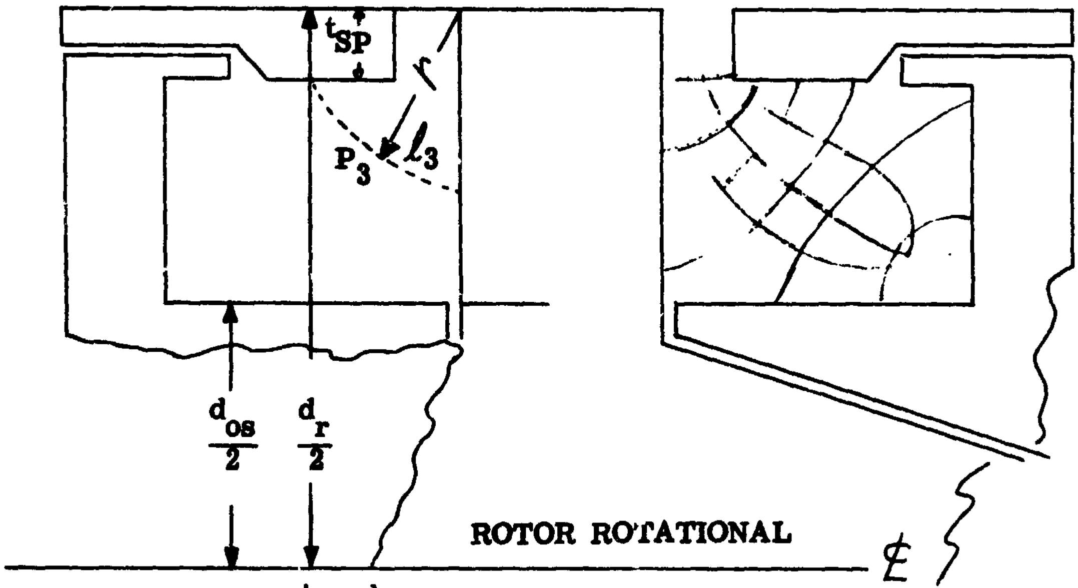
When (6) $\geq$ 6 and $b_{np}(end) = b_{np}(mid)$

$$P_4 = 3.19 \frac{\left[\frac{(d_r) - d_{os})}{2} - (T_{sp})\right]\left[(\ell_{np}) + (\ell_1)\right](P)}{(\ell_{4a})}$$

$$= 3.19 \frac{\left[\frac{(11a) - (78)}{2} - (78)\right]\left[(76) + (80a)\right](6)}{(83)}$$

Where $\ell_{4a} = \left[\frac{(d_r)}{2} - (T_{sp})\right] \sin\frac{2\pi}{(P)}\left[1 - \frac{(\alpha)}{4}\right] - \frac{(b_{np}(end)}{2}$

$$= \left[\frac{(11a)}{2} - (78)\right] \sin\frac{2\pi}{(6)}\left[1 - \frac{(77)}{4}\right] - \frac{(76)}{2}$$

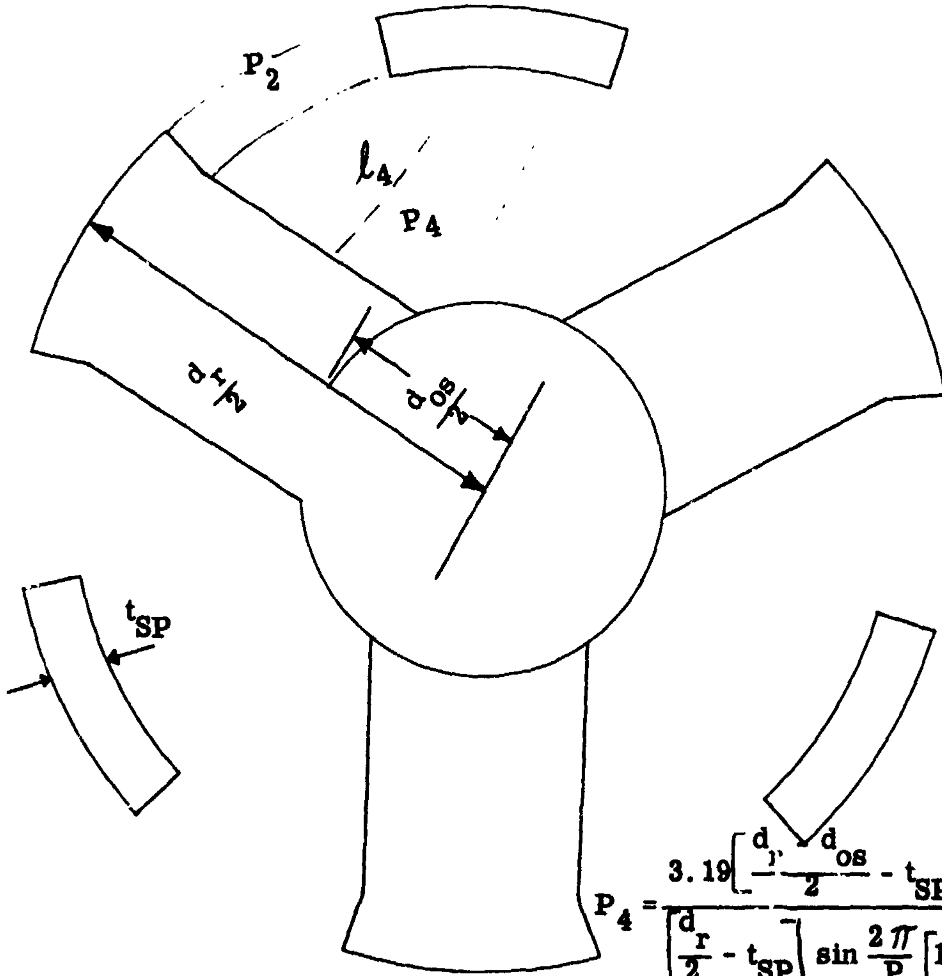


$$r_{\text{above}} = \frac{d_r - d_{os}}{4}$$

$$\ell_3 = \left(\frac{d_r - d_{os}}{4} \cdot \frac{\pi}{2}\right) - t_{SP} = (d_r - d_{os})\frac{\pi}{8} - t_{SP}$$

$$P_3 = \frac{3.19\, b_{RP}\,(h_{RP} - t_{SP})\, P}{\ell_3}$$

Figure L-6



$$P_4 = \frac{3.19\left[\frac{d_r}{2} - \frac{d_{os}}{2} - t_{SP}\right](\ell_{NP} + \ell_1)\,P}{\left[\frac{d_r}{2} - t_{SP}\right]\sin\frac{2\pi}{P}\left[1 - \frac{\alpha}{4}\right] - \frac{b_{NP}}{2}}$$

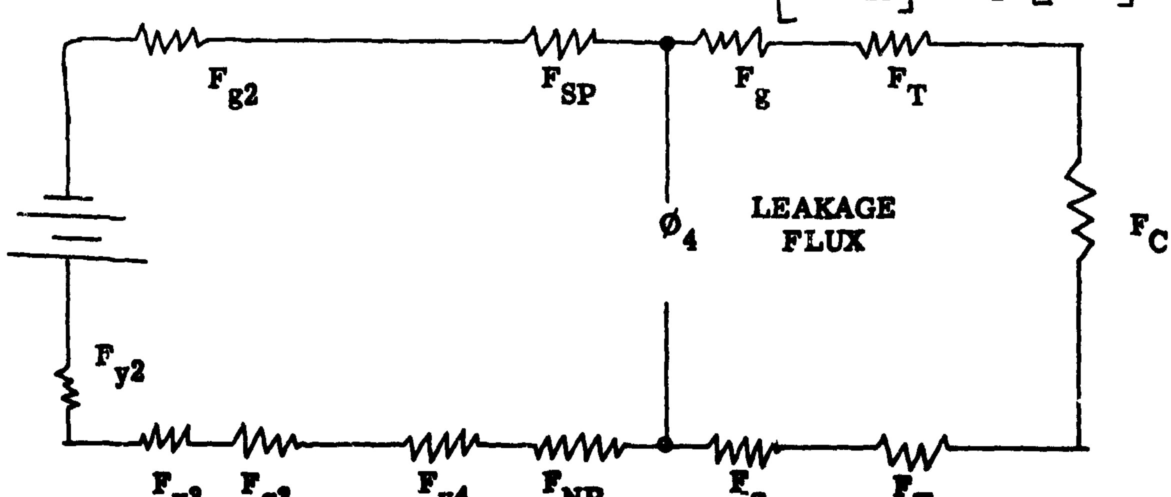
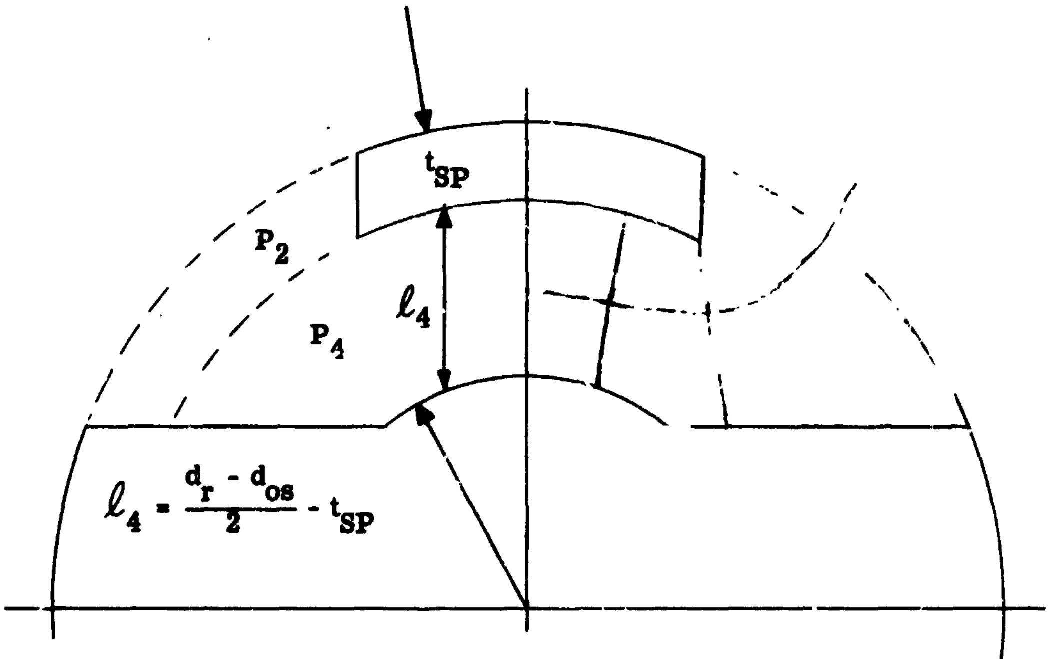
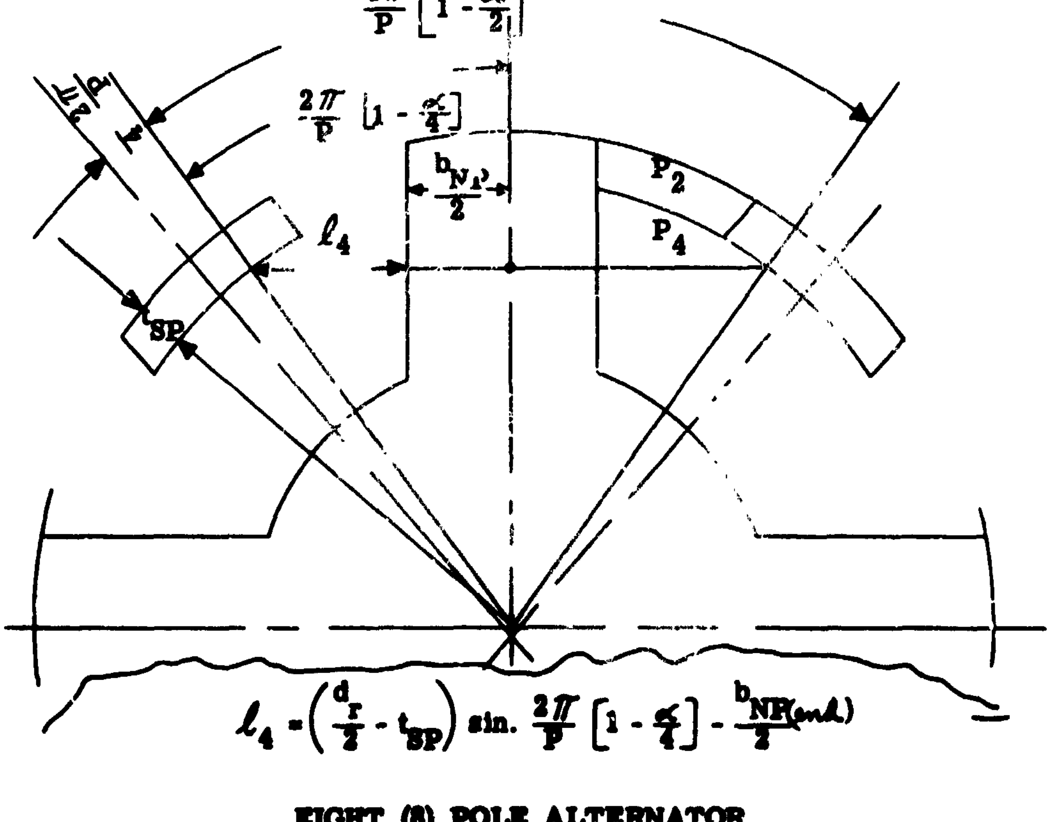


Figure L-7



$$\ell_4 = \frac{d_r - d_{os}}{2} - t_{SP}$$

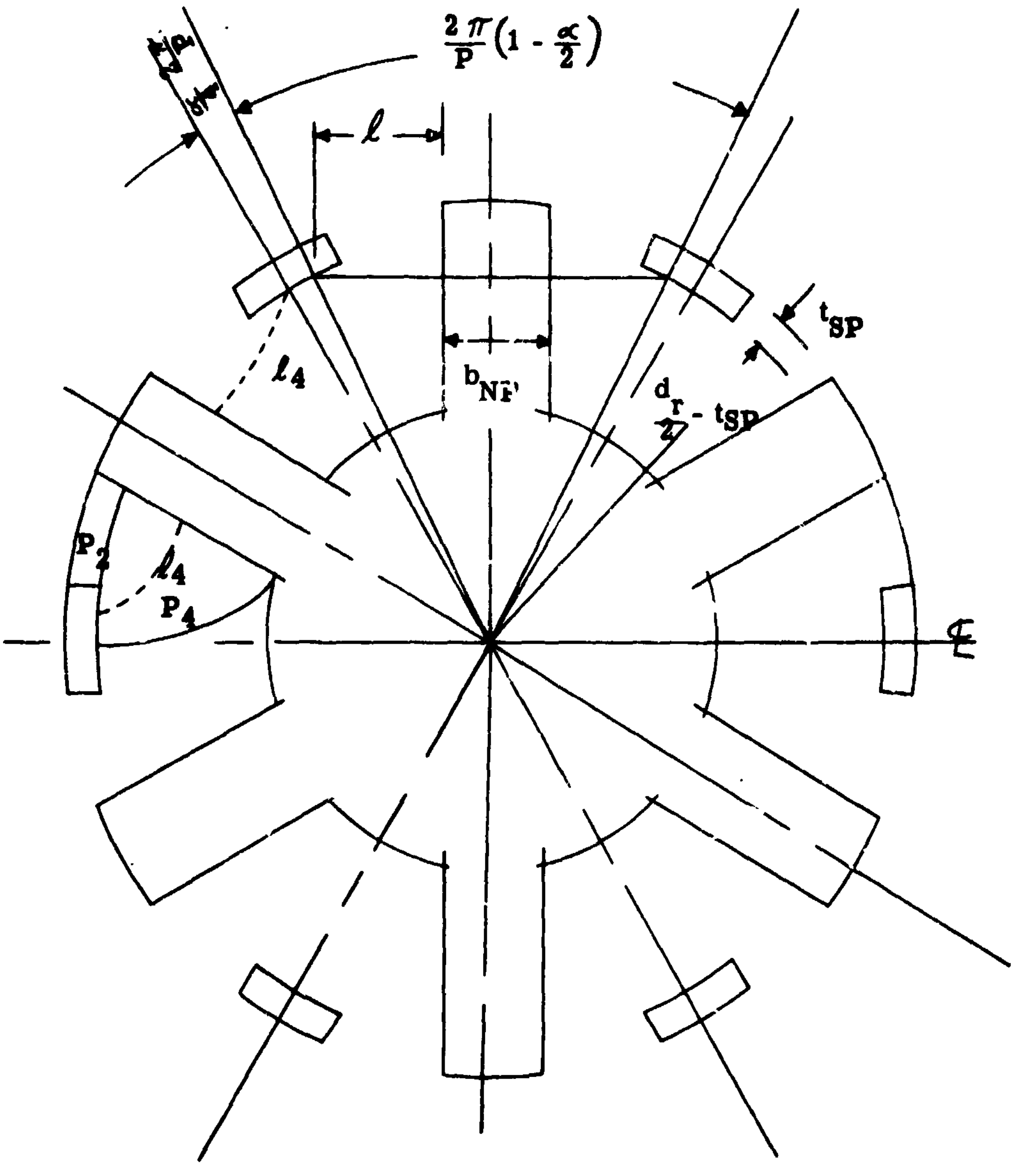
FOUR (4) POLE ALTERNATOR



$$\ell_4 = \left(\frac{d_r}{2} - t_{SP}\right) \sin. \frac{2\pi}{P}\left[1 - \frac{\alpha}{4}\right] - \frac{b_{NP(end)}}{2}$$

EIGHT (8) POLE ALTERNATOR

Figure L-8



TWELVE (12) POLE ALTERNATOR

$$\ell_4 = \left(\frac{d_r}{2} - t_{SP}\right) \sin \frac{2\pi}{P}\left[1 - \frac{\alpha}{4}\right] - \frac{b_{NP(end)}}{2}$$

Figure L-9

When (6) $\geq$ 6 and b_{np}(end) $\neq$ b_{np}(mid)

$$P_4 = 6.28 \frac{\left[\frac{(d_r)}{2}-(T_{sp})\right]\left[\frac{1}{4}\sqrt{\left[(b_{np}(mid)-(b_{np}(end)\right]^2+(\ell_{np})^2} + \frac{(\ell_1)}{2}\right](P)}{(\ell_{4a})}$$

$$= 6.28 \frac{\left[\frac{(11a)}{2}-(78)\right]\left[\frac{1}{4}\sqrt{\left[(76)-(76)\right]^2 + (76)^2} + \frac{(80a)}{2}\right](6)}{(83)}$$

(84) | P_5 | <u>COIL LEAKAGE PERMEANCE TO A NORTH POLE</u> - This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure 10 for location.

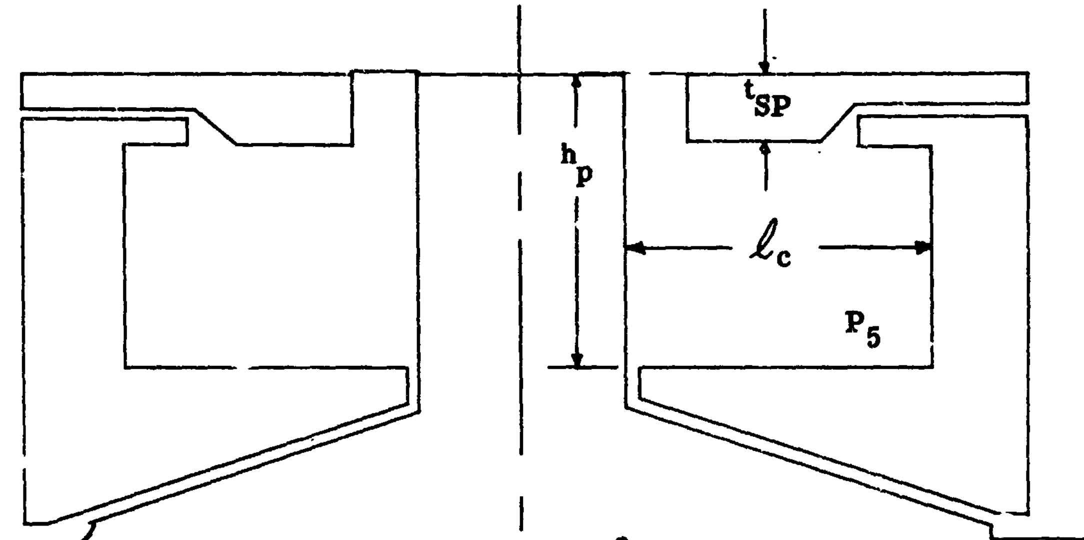
$$P_5 = 3.19 \frac{(b_{np}\ end)(\ell_6)\ \frac{2}{3}\ (P)}{(\ell_c)}$$

$$= 3.19 \frac{(76)(85)\ \frac{2}{3}\ (6)}{(84)}$$

Where ℓ_c = length of leakage path P_5 and must be specified on the input sheet. Refer to Figure L-10 for location.

NOTE: This covers the leakage for both ends of rotor.

(85) | P_6 | <u>COIL LEAKAGE PERMEANCE TO SOUTH POLE</u> - This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure L-11 for location.



$$P_5 = \frac{3.19\ b_P\ (\ell_6)\,\frac{2}{3}\,(\ P)}{\ell_c}$$

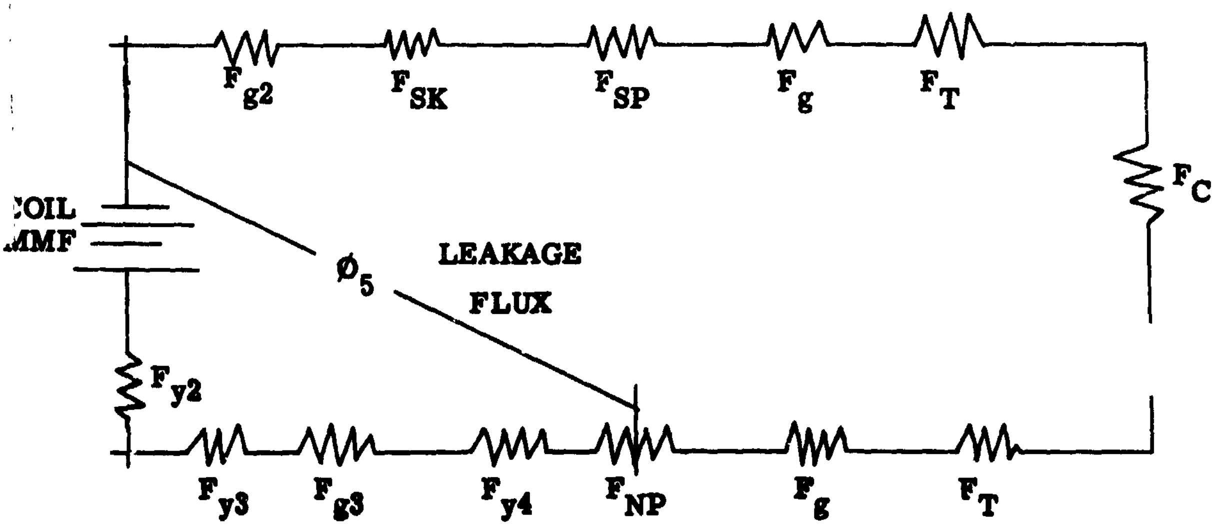
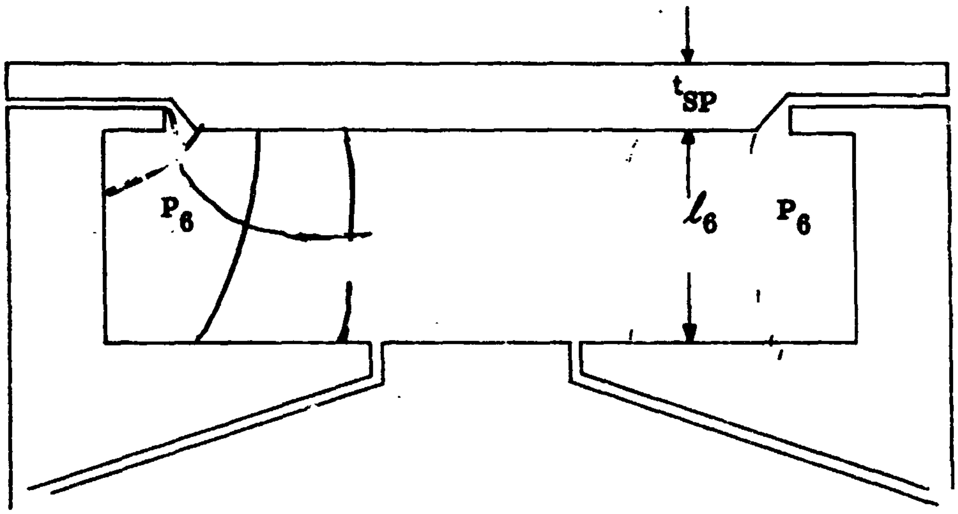
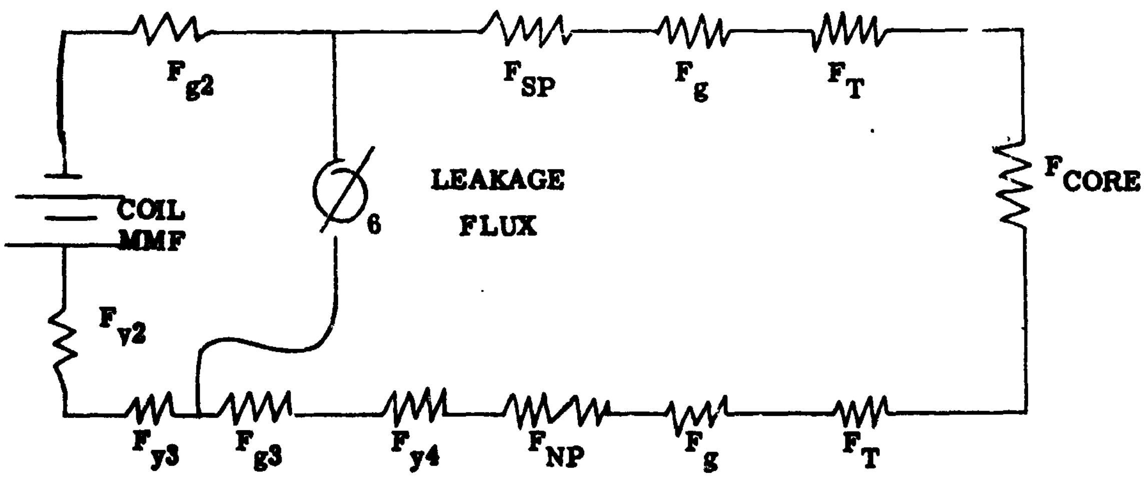


Figure L-10



FLUX LEAKAGE ACROSS FIELD COILS

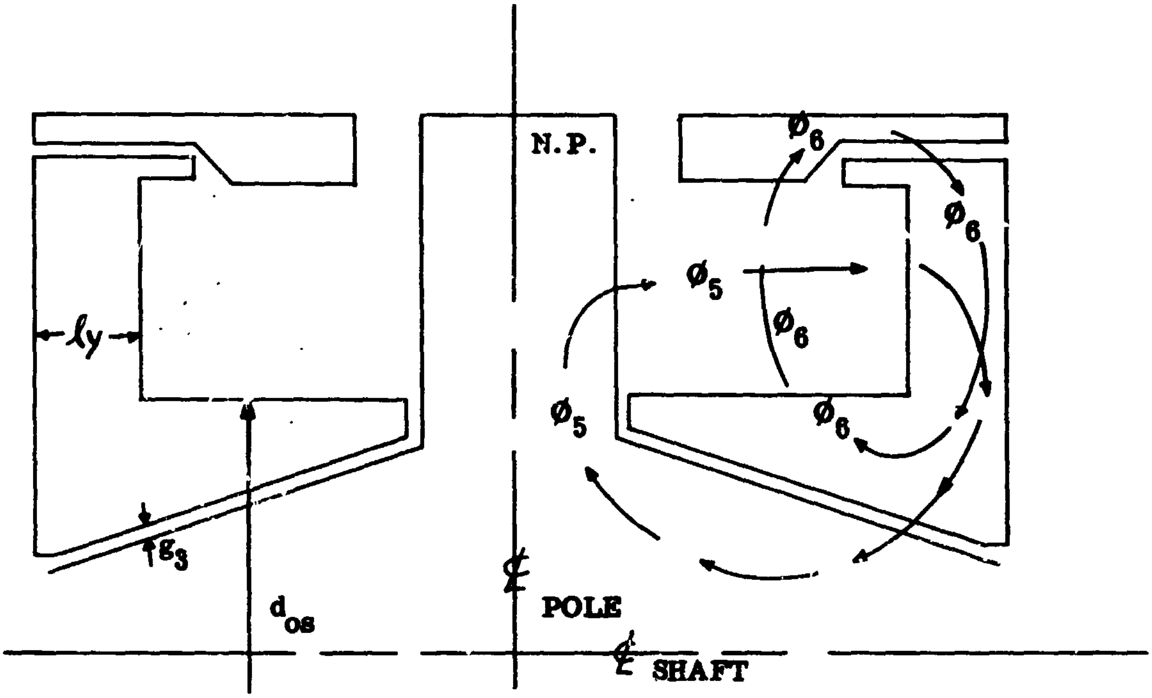


$$P_6 = \frac{3.19\, \ell_c\, \alpha\, (d_r - 2t_{SP})\, \frac{\pi}{P}(P)}{\ell_6}$$

$$= \frac{3.19\, \ell_c\, \alpha\, (d_r - 2t_{SP})\, \pi}{\ell_6}$$

Figure L-11

Leakage Fluxes ϕ_5 and ϕ_6
(Leakage across the field coil ϕ_6, and through the field coil ϕ_5)



d_{os} = diameter of outer shaft

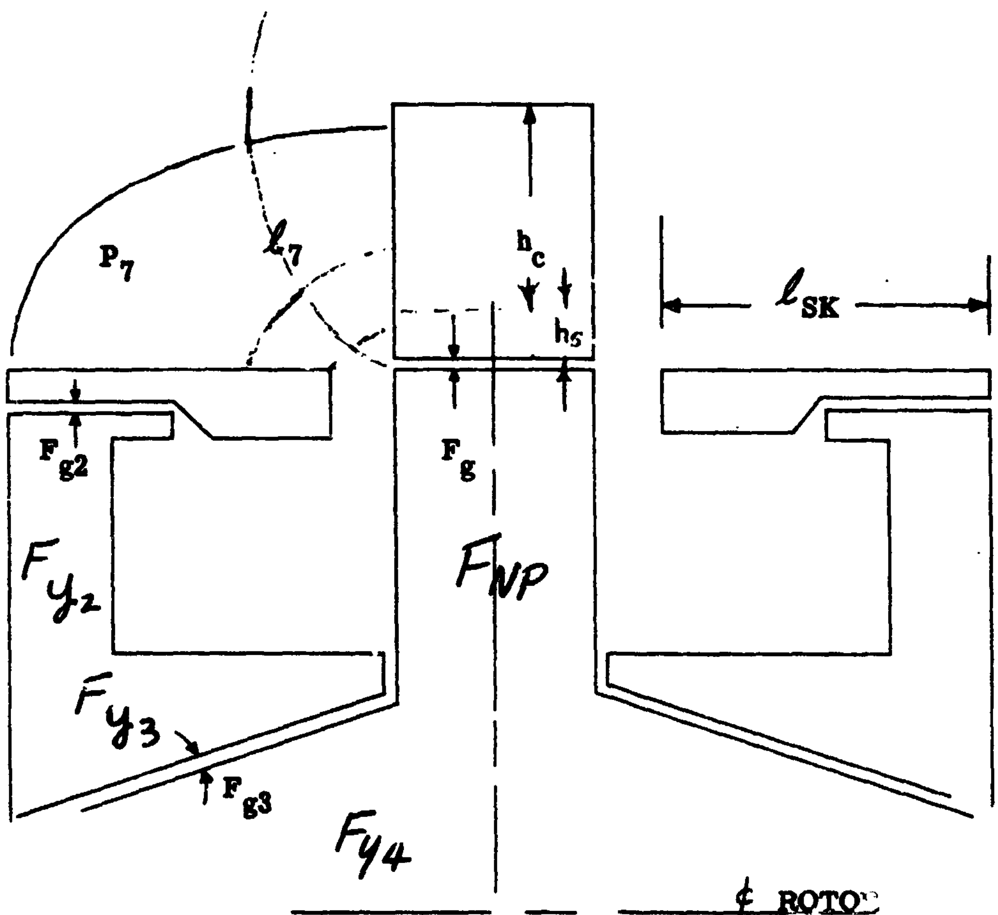
A_{y2} = area of yoke at smallest section

$A_{y2} = (d_{os})(\ell y)\pi$

The leakage flux ϕ_5 and ϕ_6 add to the flux in the yoke member y_2 but of the two leakage fluxes, only ϕ_5 adds to the flux crossing air gap g_3.

Figure L-12

LEAKAGE FLUX FROM STATOR BACK-IRON TO ROTOR SKIRT - PATH 7



$$P_7 = \frac{3.19\,(d_r + h_c)\,(h_c + \ell_{SK})}{2h_c}$$

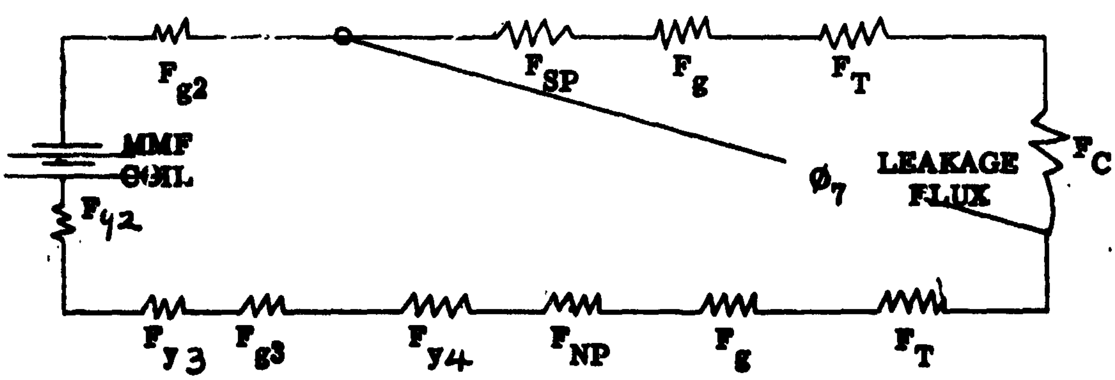


Figure L-13

$$P_6 = \frac{3.19(\ell_c)(\alpha)\left[(d_r)-2(T_{sp})\right]\frac{\pi}{(P)}(P)}{(\ell_6)}$$

$$= \frac{3.19(84)(77)\left[(11a)-2(78)\right]\frac{\pi}{(6)}(6)}{(85)}$$

Where ℓ_6 = Length of leakage path P_6 and must be specified on the input sheet. Refer to Figure L-11 for location.

NOTE: This covers the leakage for both ends of the rotor.

(86) P_7 STATOR CORE TO ROTOR SKIRT FLUX LEAKAGE -

Permeance path. This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure L-13 for location.

$$P_7 = 3.19\,\frac{\frac{\pi}{4}\left[(d_r)+(h_c)+(h_s)\right]\left[(h_c)+(h_s)+(\ell_{sk})\right]}{(\ell_7)}$$

$$P_7 = 3.19\,\frac{\frac{\pi}{4}\left[(11a)+(24)+(22)\right]\left[(24)+(22)+(78)\right]}{(86)}$$

Where $\ell_7 = \frac{\pi\left[(h_c)+(h_s)\right]}{2} = \frac{\pi\left[(24)+(22)\right]}{2}$

The leakage is from 1/2 the stator end surface calculated on each side of the stator, making the total leakage surface calculated as follows:

$$\text{Area} = \pi\left[(d_r) + (h_c) + (h_s)\right]\left[\frac{(h_c) + (\ell_{sk})}{2}\right]$$

However, 1/2 of the leakage is useful and generates voltage in the stator conductors. So for tooth density, pole density and air-gap flux calculations, the leakage flux area is:

$$\text{Area} = \frac{1}{2}\pi\left[(d_r) + (h_c) + (h_s)\right]\left[\frac{(h_c) + (\ell_{sk})}{2}\right]$$

$$= \frac{\pi}{4}\left[(d_r) + (h_c) + (h_s)\right]\left[(h_c) + (h_s) + (\ell_{sk})\right]$$

$$= \frac{\pi}{4}\left[(11a) + (24) + (22)\right]\left[(24) + (22) + (78)\right]$$

(87) -- <u>NO LOAD SATURATION CALCULATIONS</u> - The next set of calculations deals with the no load saturation.

When the no load saturation data is required at various voltages, insert <u>1.</u> on input sheet for "No Load Sat." The computer will then calculate no load saturation @ 80, 90, 100, 110, 120, 130, 140, 150 and 160% of rated volts. When the complete saturation data is not necessary, insert <u>0.</u> on input sheet and the computer will calculate the 100% volt data.

(88) ϕ_T

TOTAL FLUX IN KILOLINES

$$\phi_T = \frac{6(E)10^6}{(C_W)(N_e)(RPM)} \quad \frac{6(3)10^6}{(72)(45)(7)}$$

(89) ϕ'_7

ESTIMATED VALUE OF LEAKAGE FLUX ϕ_7

$$\phi'_7 = .01\ (\phi_T)$$

$$= .01\ (88)$$

Complete the next set of calculations Item (90) through Item (99) using ϕ'_7, the estimated value. If the calculated value (ϕ_7) Item (99) agrees within $\pm10\%$ of the estimated value (ϕ'_7), Item (89), use all of the items, (90) through (99) as final and proceed on with calculations. If the calculated value ϕ_7, Item (99), does not agree within $\pm10\%$ of the estimated value (ϕ'_7) then recalculate items (89) through (99) using ϕ_7 item (99) as the estimated value for ϕ'_7.

(90) ϕ'_T

ESTIMATED TOTAL FLUX - including estimated value of ϕ_7

$$\phi'_T = (\phi_T) + (\phi'_7)$$

$$= (88) + (89)$$

(91) B'_T

ESTIMATED STATOR TOOTH DENSITY

$$B'_T = \frac{\phi'_T}{(Q)(\ell_s)(b_t\ 1/3)} = \frac{(90)}{(23)(17)(57a)}$$

(92) ϕ_P

FLUX PER POLE

$$\phi_P = \frac{(\phi_T)(C_P)}{(P)} \quad \frac{(88)(73)}{(6)}$$

(93)	ϕ'_P	ESTIMATED FLUX PER POLE including leakage flux ϕ_7' $$\phi'_P = \frac{(\phi'_T)(C_P)}{(P)} = \frac{(90)(73)}{(6)}$$
(94)	B'_c	ESTIMATED STATOR CORE DENSITY $$B'_c = \frac{(\phi'_P)}{2(h_c)(\ell_s)} = \frac{(93)}{2(24)(17)}$$
(95)	B'_g	ESTIMATED MAIN GAP DENSITY $$B'_g = \frac{\phi'_T}{\pi(d)(\ell)} = \frac{(90)}{\pi(11)(13)}$$
(96)	F'_g	ESTIMATED MAIN GAP AMPERE TURNS $$F'_g = \frac{(B'_g)(g_e)}{3.19} \times 10^3 = \frac{(95)(69)}{3.19} \times 10^3$$
(97)	F'_T	ESTIMATED STATOR TOOTH AMPERE TURNS $$F'_T = (h_s)\left[\text{NI/inch at density } (B'_T)\right]$$ $$= (22)\left[\begin{array}{l}\text{look up on stator magnetization curve} \\ \text{given in (18) at density (91)}\end{array}\right]$$
(98)	F'_c	ESTIMATED STATOR CORE AMPERE TURNS $$F'_c = \left\{\frac{\pi\left[(D) - (h_c)\right]}{4(P)}\right\}\left[\text{NI/inch at density } (B'_c)\right]$$ $$F'_c = \left\{\frac{\pi\left[(12)-(24)\right]}{4(6)}\right\}\left[\begin{array}{l}\text{Look up on stator magnetization} \\ \text{curve at density (94)}\end{array}\right]$$

(99) $\emptyset_7$ CALCULATED VALUE OF LEAKAGE FLUX through path ℓ_7.

See Figure L13. Leakage from stator back iron to rotor skirt. (In kilolines).

$$\emptyset_7 = (P_7)\left[(F'_g) + (F'_T) + (F'_c)\right] \times 10^{-3}$$

$$= (86)\left[(96) + (97) + (98)\right] \times 10^{-3}$$

Next compare the estimated value of $\emptyset'_7$, Item (89) with the calculated value of $\emptyset_7$, Item (99).

If $1.10\ (\emptyset_7) \geqq (\emptyset'_7) \geqq .90\ (\emptyset_7)$ then use $\emptyset_7$ and continue with calculations. If $\emptyset_7$ does not fall within the limits given above, then recalculate Item (89) through (99) using $\emptyset_7$, Item (99) as estimated value of $\emptyset'_7$.

(100) $\emptyset_1$ POLE HEAD END LEAKAGE FLUX. (In kilolines)

$$\emptyset_1 = (P_1)\left[2(F'_g) + 2(F'_T) + 2(F'_c)\right] \times 10^{-3}$$

$$= (80)\left[2(96) + 2(97) + 2(98)\right] \times 10^{-3}$$

(101) $\emptyset_2$ POLE HEAD SIDE LEAKAGE. (In kilolines)

$$\emptyset_2 = (P_2)\left[2(F'_g) + 2(F'_T) + 2(F'_c)\right] \times 10^{-3}$$

$$= (81)\left[2(96) + 2(97) + 2(98)\right] \times 10^{-3}$$

(102) $\emptyset_3$ POLE BODY END LEAKAGE. (In kilolines)

$$\emptyset_3 = (P_3)\left[2(F'_g) + 2(F'_T) + 2(F'_c)\right] \times 10^{-3}$$

$$= (82)\left[2(96) + 2(97) + 2(98)\right] \times 10^{-3}$$

(103)	$\emptyset_4$	POLE BODY SIDE LEAKAGE. (In kilolines)
(104)	B'_{np}	NORTH POLE FLUX DENSITY - First calculation.
(105)	B_{sp}	SOUTH POLE FLUX DENSITY
(106)	F'_{np}	NORTH POLE AMPERE TURN DROP - First calculation.

(103) $\emptyset_4$ — POLE BODY SIDE LEAKAGE. (In kilolines)

$$\emptyset_4 = (P_4)\left[2(F'_g) + 2(F'_T) + 2(F'_c)\right] \times 10^{-3}$$

$$= (83)\left[2(96) + 2(97) + 2(98)\right] \times 10^{-3}$$

(104) B'_{np} — NORTH POLE FLUX DENSITY - First calculation. This item will be recalculated in Step (116) including flux $\emptyset_5$.

$$B'_{np} = \frac{\emptyset_p + \dfrac{(\emptyset_1) + (\emptyset_2) + (\emptyset_3) + (\emptyset_4) + (\emptyset_7)}{(P)}}{(a_{np})}$$

$$= \frac{(92) + \dfrac{(100) + (101) + (102) + (103) + (99)}{(6)}}{(79)}$$

(105) B_{sp} — SOUTH POLE FLUX DENSITY

$$B_{sp} = \frac{(\emptyset_p) + \dfrac{(\emptyset_1) + (\emptyset_2) + (\emptyset_3) + (\emptyset_4) + (\emptyset_7)}{(P)}}{2(a_{sp})}$$

$$= \frac{(92) + \dfrac{(100) + (101) + (102) + (103) + (99)}{(6)}}{2\,(79a)}$$

(106) F'_{np} — NORTH POLE AMPERE TURN DROP - First calculation. This item will be recalculated in Item (117) including Flux $\emptyset_5$.

$$F'_{np} = (h_{np})\left[\text{NI/inch at density } (B'_{np})\right]$$

$$= (78)\left[\begin{array}{l}\text{Look up on north pole magnetization}\\ \text{curve given in (18) at density (104).}\end{array}\right]$$

(107) F_{sp} **SOUTH POLE AMPERE TURN DROP**

When $b_{np}(end) = b_{np}(mid)$

$$F_{sp} = \frac{(\ell_{sp})}{3}\left[\text{NI/inch at density } (B_{sp})\right]$$

$$F_{sp} = \frac{(76)}{3}\left[\begin{array}{l}\text{Look up on south pole or tube magneti-}\\ \text{zation curve given in (18, at density (105)}\end{array}\right]$$

When $b_{np}(end) \neq b_{np}(mid)$

$$F_{sp} = \frac{(\ell_{sp})}{2}\left[\text{NI/inch at density } (B_{sp})\right]$$

$$= \frac{(76)}{2}\left[\begin{array}{l}\text{Look up on south pole or tube magneti-}\\ \text{zation curve given in (18) at density (105)}\end{array}\right]$$

(108) $\emptyset_{g2}$ **AUXILIARY AIR GAP g_2 FLUX**

$$\emptyset_{g2} = \frac{\left[(\emptyset_p)(P)\right] + (\emptyset_1) + (\emptyset_2) + (\emptyset_3) + (\emptyset_4) + (\emptyset_7)}{4}$$

$$= \frac{\left[(92)(6)\right] + (100) + (101) + (102) + (103) + (99)}{4}$$

(109) B'_{g2} **FLUX DENSITY IN AUXILIARY GAP** - First calculation.

$$B'_{g2} = \frac{(\emptyset_{g2})}{(A_{g2})} = \frac{(108)}{(70)}$$

(110) F'_{g2} **AMPERE TURN DROP ACROSS AUXILIARY AIR GAP** -

First calculation.

$$F'_{g2} = \frac{(B'_{g2})(g_2)}{3.19} \times 10^3 = \frac{(109)([illegible]a)}{3.19} \times 10^3$$

(112)	A_{y4}	AREA OF SHAFT - in inches^2 - cross-sectional to flux in shaft.

$$A_{y4} = \left[\frac{\pi(dos)^2}{4}\right] - \left[\frac{\pi(d_Q)^2}{4}\right]$$

$$= \frac{\pi(78)^2}{4} - \frac{\pi(78)^2}{4}$$

NOTE: When a solid shaft is used, the second term will drop out because $d_Q = 0$.

(113)	B_{y4}	FLUX DENSITY OF SHAFT

$$B_{y4} = \frac{(\emptyset_p)(P) + (\emptyset_1) + (\emptyset_2) + (\emptyset_3) + (\emptyset_4) + (\emptyset_7)}{4\ (A_{y4})}$$

$$= \frac{(92)(6) + (100) + (101) + (102) + (103) + (99)}{4\ (112)}$$

(114)	F_{y4}	SHAFT AMPERE TURN DROP

$$F_{y4} = (\ell_{y4})\left[\text{NI/inch at density } (B_{y4})\right]$$

$$= (78)\left[\begin{array}{l}\text{Look up on shaft magnetization curve} \\ \text{given in (18) at density (113)}\end{array}\right]$$

NOTE: This magnetization curve for shaft and spider can be synthesized into one curve when the effective cross-sectional area of the shaft is made up of two separate materials. This does not affect the present computer program. Only the magnetization curve that is submitted must be corrected.

(115) ϕ'_5 LEAKAGE FLUX FROM NOTH POLE (SPIDER POLE) THROUGH THE FIELD COIL - First calculation.

Items (116) through (118) will be calculated using this value of ϕ'_5. A new value for ϕ_5 will then be calculated in Item (118). This new value must be within $\pm 10\%$ of Item (115) or calculation (115) through (118) must be repeated using the new value of (F_{np}) Item (117) in (115).

$$\phi'_5 = P_5\left[(F'_{g2})+(F_{sp})+2(F'_g)+2(F'_T)+ 2(F'_c)+(F'_{np})\right] \times 10^{-3}$$

$$= (84)\left[(110)+(107)+2(96)+2(97)+2(98)+(106)\right] \times 10^{-3}$$

(116) B_{np} NORTH POLE FLUX DENSITY - This value will supersede the value calculated in (104).

$$B_{np} = \frac{\phi_p + \dfrac{(\phi_1)+(\phi_2)+(\phi_3)+(\phi_4)+(\phi_7)+(\phi'_5)}{(P)}}{(a_{np})}$$

$$= \frac{(92) + \dfrac{(100)+(101)+(102)+(103)+(99)+(115)}{(6)}}{(79)}$$

(117) F_{np} NORTH POLE AMPERE TURN DROP - This value will supersede the value calculated in (106).

$$F_{np} = h_{np}\left[\text{NI/inch at density } (B_{np})\right]$$

$$= (78)\left[\begin{array}{l}\text{Look up on north pole magnetization}\\ \text{curve given in (18) at density (116).}\end{array}\right]$$

(118) | ϕ_5 | LEAKAGE FLUX FROM NORTH POLE (spider pole) through the field coil. Second Calculation.

$$\phi_5 = P5\left[(F'_{g2})+(F_{sp})+2(F'_g)+2(F'_T)+2(F'_c)+(F_{np})\right] \times 10^{-3}$$

$$= (84)\left[(110)+(107)+2(96)+2(97)+2(98)+(117)\right] \times 10^{-3}$$

This item, ϕ_5, must be within $\pm 10\%$ of the first calculatior ϕ_5, Item (115), or must recalculate Items (115) through (118) using (F_{np}), Item (117), in the second calculation of (115).

(119) | B_{g3} | FLUX DENSITY IN AIR GAP g_3

$$B_{g3} = \frac{(\phi_p)(P)+(\phi_1)+(\phi_2)+(\phi_3)+(\phi_4)+(\phi_7)+(\phi_5)}{4(A_{g3})}$$

$$= \frac{(92)(6)+(100)+(101)+(102)+(103)+(99)+(118)}{4(70a)}$$

(120) | F_{g3} | AMPERE TURN DROP ACROSS GAP g_3

When (59b) = 2.0 calculate as follows:

$$F_{g3} = \frac{B_{g3}}{3.19}(g_3) \times 10^3 = \frac{(119)}{3.19}(59c) \times 10^3$$

When (59b) = 1.0, calculate as follows:

$$F_{g3} = \frac{B_{g3}}{3.19}(g_{3e}) \times 10^3 = \frac{(119)}{3.19}(59f) \times 10^3$$

(121) | ϕ_6 | LEAKAGE FLUX ACROSS FIELD COIL FROM INNER YOKE TO SOUTH POLE TUBE in kilolines.

$$\emptyset_6 = (P_6)\left[(F_{sp})+2(F'_{g})+2(F'_{T})+2(F'_{c})+(F_{np})+(F_{y4})+(F_{g3})\right] \times 10^{-3}$$

$$= (85)\left[(107)+2(96)+2(97)+2(98)+(117)+(114)+(120)\right] \times 10^{-3}$$

(122)	B_{g2}	FINAL FLUX DENSITY IN AUXILIARY GAP g_2
(123)	F_{g2}	FINAL F_{g2}
(124)	A_{y2}	CROSS-SECTIONAL AREA OF YOKE location per Figure L12
(125)	B_{y2}	DENSITY OF COIL YOKE
(126)	F_{y2}	AMPERE TURN DROP IN COIL YOKE

(122) B_{g2} FINAL FLUX DENSITY IN AUXILIARY GAP g_2

$$= \frac{(\emptyset_p)(P)+(\emptyset_1)+(\emptyset_2)+(\emptyset_3)+(\emptyset_4)+(\emptyset_7)+(\emptyset_6)}{4(A_{g2})}$$

$$= \frac{(92)(6)+(100)+(101)+(102)+(103)+(99)+(121)}{4(69a)}$$

(123) F_{g2} FINAL $F_{g2} = \frac{(B_{g2})(g_2)}{3.19} \times 10^3 = \frac{(122)(59a)}{3.19} \times 10^3$

(124) A_{y2} CROSS-SECTIONAL AREA OF YOKE location per Figure L12

$$A_{y2} = \pi(d_{os})(\ell_y)$$
$$= \pi(78)(78)$$

(125) B_{y2} DENSITY OF COIL YOKE

$$B_{y2} = \frac{(\emptyset_p)(P) + (\emptyset_1)+(\emptyset_2)+(\emptyset_3)+(\emptyset_4)+(\emptyset_7)+(\emptyset_5)}{4(A_{y2})}$$

$$= \frac{(92)(6)+(100)+(101)+(102)+(103)+(99)+(118)}{4(124)}$$

(126) F_{y2} AMPERE TURN DROP IN COIL YOKE

$$F_{y2} = \frac{(h_y)}{3}\left[\text{NI/inch at density } (B_{y2})\right]$$

$$= \frac{(78)}{3}\left[\begin{array}{l}\text{Look up on yoke magnetization curve} \\ \text{given in (18) at a density (125)}\end{array}\right]$$

(127)	F_{NL}	TOTAL AMPERE TURNS AT NO LOAD PER CIRCUIT $F_{NL} = 2(F'_g)+2(F'_T)+2(F'_c)+(F_{np})+(F_{sp})+(F_{g2})+(F_{y2})+(F_{g3})+(F_{y4})$ $= 2\left[(96)+(97)+(98)\right]+(117)+(107)+(123)+(126)+(120)+(114)$
(127a)	I_{FNL}	NO LOAD FIELD CURRENT PER COIL $I_{FNL} = \frac{F_{NL}}{N_F} = \frac{(127)}{(146)}$
(127b)	E_{FNL}	NO LOAD FIELD VOLTS PER COIL $E_{FNL} = (I_{FNL})(R_{F(cold)})$ $= (127a)(154)$
(127c)	S_F	CURRENT DENSITY IN FIELD CONDUCTOR - At no load
(128)	A	AMPERE CONDUCTORS per inch
(129)	X	REACTANCE FACTOR -
(130)	X_ℓ	LEAKAGE REACTANCE -
(131)	X_{ad}	REACTANCE - direct axis - This is the fictitious reactance due to armature reaction in the direct axis. $X_{ad} = \frac{.9(n_e)(I_{ph})(C_m)(K_d)}{P\left[2(F'_g)+(F_{g2})+(F_{g3})\right]} \times 100$ $X_{ad} = \frac{.9(45)(8)(74)(43)}{6\left[2(96)+(123)+(120)\right]} \times 100$

(132)	X_{aq}	REACTANCE - Quadrature axis - This is the fictitious reactance due to armature reaction in the quadrature axis. $$X_{aq} = \frac{(C_q)(X_{ad})}{(C_m)(C_1)}$$ $$X_{aq} = \frac{(75)(131)}{(74)(71)}$$
(133)	X_d	SYNCHRONOUS REACTANCE - direct axis -
(134)	X_q	SYNCHRONOUS REACTANCE - quadrature axis - The steady
(135)	--	**DAMPER SLOT DIMENSIONS**
(136)	--	DAMPER BAR DIA OR WIDTH in inches
(137)	h_{bl}	DAMPER BAR THICKNESS in inches -
(138)	n_b	NUMBER OF DAMPER BARS PER POLE
(139)	ℓ_b	DAMPER BAR LENGTH in inches
(140)	τ_b	DAMPER BAR PITCH in inches
(141)	ρ_D	RESISTIVITY of damper bar @ 20°C in micro ohm-inches -
(142)	$X_D{}^oC$	DAMPER BAR TEMP °C -
(143)	ρ_D (hot)	RESISTIVITY of damper bar @ $X_D{}^oC$

(144)	a_{cd}	CONDUCTOR AREA OF DAMPER BAR -
(145)	V_r	PERIPHERAL SPEED -
(146)	N_F	NUMBER OF FIELD TURNS PER COIL
(147)	ℓ_{tF}	MEAN LENGTH OF FIELD TURN
(148)	--	FIELD CONDUCTOR DIA OR WIDTH in inches
(149)	--	FIELD CONDUCTOR THICKNESS in inches -
(150)	$X_f{}^oC$	FIELD TEMP IN ^oC -
(151)	ρ_f	RESISTIVITY of field conductor @ 20^oC in micro ohm-inches.
(152)	ρ_f (hot)	RESISTIVITY of field conductor at $X_f{}^oC$
(153)	a_{cf}	CONDUCTOR AREA OF FIELD WINDING -
(154)	R_f (cold)	COLD FIELD RESISTANCE @ 20^oC per coil
		$\text{:old)} = (\rho_f) \dfrac{(N_F)(\ell_{tF}) \times 10^{-6}}{(a_{cf})} = (151) \dfrac{(146)(147)}{(153)} \times 10^{-6}$

(155) R_f (hot) HOT FIELD RESISTANCE - Calculated at $X_f{}^{o}C$ (103) - (Per coil)

$$R_{f(hot)} = \rho_{f\,hot} \frac{(N_f)(\ell_{tf}) \times 10^{-6}}{(a_{cf})} = (152)\frac{(146)(147) \times 10^{-6}}{(153)}$$

(156) -- WEIGHT OF FIELD COIL in lbs. - per coil

The answer is given in lbs. based on the density of copper. If any other material is used, the answer on the output sheet can be converted by the designer by multiplying by the ratio of densities.

$$\#\text{'s of copper} = .321\,(N_F)(\ell_{tf})(a_{cf})$$

$$= .321\,(146)(147)(153)$$

(157) -- WEIGHT OF ROTOR IRON -

(158) λ_b PERMEANCE OF DAMPER BAR -

(159) λ_{pt} PERMEANCE OF END PORTION OF DAMPER BARS

$$\lambda_{pt} = 6.38\left\{\frac{(b_{np(end)} - (\tau_b)\left[(n_b) - 1\right]}{3(g_e)}\right\}$$

$$= 6.38\left\{\frac{(76) - (140)\left[(138) - 1\right]}{3(69)}\right\}$$

(160)	X_F	**THE EFFECTIVE FIELD LEAKAGE REACTANCE** - The reactance which added to the stator leakage reactance gives the transient reactance X'_{du}.

When unit fundamental armature ampere turns are suddenly applied on the direct axis, an initial field current (I_f) will be induced. The value of this initial field current will be just enough to make the net flux interlinking the field because of the field current and the armature current zero. The field ampere turns will equal the armature ampere turns.

$$X_F = X_{ad}\left[1 - \frac{\frac{C_1}{C_m}}{2C_p + \frac{4}{\pi}\ \frac{\lambda F}{\lambda a}}\right]$$

$$X_F = (131)\left[1 - \frac{\frac{(71)}{(74)}}{2(73) + \frac{4}{\pi}\ \frac{(161a)}{(160)}}\right]$$

$$\lambda_a = \frac{6.38d}{P_{ge}'} = \frac{6.38(11)}{(6)\,(160)}$$

Where:

$$g'_e = (g_e)\left[\frac{2(F'_g) + (F_{g2}) + (F_{g3})}{2(F'_g)}\right]$$

$$= (69)\left[\frac{2(96) + (123) + (120)}{2(96)}\right]$$

(160a)	P_e	$$P_e = \frac{\phi_{g2} \text{ @ NL}}{(I_{fNL})(N_F) \text{ @ NL}}$$ $$P_e = \frac{(108)}{(127a)(146)}$$
(161)	L_F	**FIELD INDUCTANCE** $$L_F = 2(N_F)^2\ P_e\ 10^{-8}$$ $$= 2(146)^2\ (160a) \times 10^{-8}$$
(161a)	λ_F	**SPECIFIC PERMEANCE OF FIELD** $$\lambda_F = \frac{P_1 + P_2 + P_3 + P_4 + P_5 + P_6}{\ell}$$ $$= \frac{(80) + (81) + (82) + (83) + (84) + (85)}{(13)}$$
(162)	λ_{Dd}	**PERMEANCE OF DAMPER BAR** - in direct axis $$\lambda_{Dd} = \left\{\cos\left[\frac{\{(n_b) - 1\}(\tau_b)\pi}{2(\tau_p)}\right]\right\}\left\{\frac{\{(\lambda_b) + (\lambda_{Pt})\}(\lambda_F)}{\lambda_b + \lambda_{Pt} + \lambda_F}\right\}$$ $$= \left\{\cos\left[\frac{\{(138) - 1\}(140)\pi}{2(41)}\right]\right\}\left\{\frac{\{(158) + (159)\}(161a)}{(158) + (159) + (161a)}\right\}$$
(163)	X_{Dd}	**DAMPER LEAKAGE REACTANCE** - in direct axis $$X_{Dd} = X(\lambda_{Dd}) = (129)(162)$$

(164)	λ_{Dq}	PERMEANCE IN QUADRATURE AXIS
(165)	X_{Dq}	DAMPER LEAKAGE REACTANCE - in quadrature axis
(166)	X'_{du}	UNSATURATED TRANSIENT REACTANCE
(167)	X'_{d}	SATURATED TRANSIENT REACTANCE
(168)	X''_{d}	SUBTRANSIENT REACTANCE in direct axis
(169)	X''_{q}	SUBTRANSIENT REACTANCE in quadrature axis
(170)	X_2	NEGATIVE SEQUENCE REACTANCE - The reactance due to the field which rotates at synchronous speed in a direction opposite to that of the rotor

$$X_2 = \frac{X_m\left[4(\Sigma) + 4(\Sigma)^2 + (n)^2\right]}{n^2 + 4\left[1 + (\Sigma)\right]^2} + X_\ell$$

$$= \frac{(170)\left[4(170) + 4(170)^2 + (170)^2\right]}{(170)^2 + 4\left[1 + (170)\right]^2} + (130)$$

Where $\Sigma = \frac{(X_D)}{(X_m)} = \frac{(170)}{(170)}$

Where $X_m = \frac{X_{ad}}{(C_1)(C_m)}\left[\frac{2(F'_g) + (F_{g2}) + (F_{g3})}{(F_{NL})}\right]$

$$= \frac{(131)}{(71)(74)} \left[\frac{2(96) + (123) + (120)}{(127)} \right]$$

For Round Slots:

$$X_D = \frac{20(X)}{(n_b)} \left[.62 + \frac{(h_{bo})}{(b_{bo})} \right] + \frac{5(X_m)}{6(n_b)^2}$$

$$= \frac{20(129)}{(138)} \left[.62 + \frac{(135)}{(135)} \right] + \frac{5(170)}{6(138)^2}$$

For Rectangular Slots:

$$X_D = \frac{20(X)}{N_b} \left[\frac{(h_{bl})}{3(b_{bl})} + \frac{(h_{bo})}{(b_{bo})} \right] + \frac{5(X_m)}{6(N_b)^2}$$

$$= \frac{20(129)}{(138)} \left[\frac{(135)}{3(135)} + \frac{(135)}{(135)} \right] + \frac{5(170)}{6(138)^2}$$

Where $n = \frac{R_D}{X_m} = \frac{(170)}{(170)}$

Where R_D = Damper bar resistance

$$= \frac{100(X)(P)(\rho_{hot})}{(f)\ (\ell_s)} \left[\frac{\ell_b}{(n_b)(a_{cd})(P)} + \frac{.637(d_{ar})}{(a_{dr})(P)^2} \right]$$

$$= \frac{100(129)(6)(143)}{(5a)\ (17)} \left[\frac{(139)}{(138)(144)(6)} + \frac{.637(170)}{(170)(6)^2} \right]$$

Where d_{dr} = mean diameter of damper end ring. Must be given on input sheet.

Where a_{dr} = cross-sectional area of damper end ring. Must be given on input sheet.

(171)	Z_2	NEGATIVE SEQUENCE IMPEDANCE - approximate calculation.
		$Z_2 = R_2 + j\ X_2 = \sqrt{R^2 + X^2}$
		$Z_2 = (171) + j(170) = \sqrt{(171)^2 + (170)^2}$
		Where: $R_2 = \dfrac{2(R_D)}{(n)^2 + 4\left[1 + (\varepsilon)\right]^2} + R_s$ (hot)
		$= \dfrac{2(170)}{(170)^2 + 4\left[1 + (170)\right]} + (54)$
(172)	X_0	ZERO SEQUENCE REACTANCE -
(173)	K_{xo}	
(174)	K_{xl}	
(175)	λ_{Bo}	
(176)	T'_{do}	OPEN CIRCUIT TIME CONSTANT - The time constant of the field winding with the stator open circuited and with negligible external resistance and inductance in the field circuit. Field resistance at room temperature (20^oC) is used in this calculation.
		$T'_{do} = \dfrac{L_F}{2(R_F)} = \dfrac{(161)}{2(154)}$

(177)	T_a	ARMATURE TIME CONSTANT -
(178)	T'_d	TRANSIENT TIME CONSTANT -
(179)	T''_d	SUBTRANSIENT TIME CONSTANT -
(180)	F_{SC}	SHORT CIRCUIT AMPERE TURNS - The field ampere turns required to circulate rated stator current when the stator is short circuited.
(181)	SCR	SHORT CIRCUIT RATIO -
(182)	I^2R_R	FIELD COIL I^2R - at no load. The copper loss in the field winding is calculated with cold field resistance at 20°C for no load condition. (Loss for 2 coils.)

$$F_{SC} = \frac{(X_d)}{100}\left[2(F'_g) + (F_{g2}) + (F_{g3})\right]$$

$$= \frac{(133)}{100}\left[2(96) + (123) + (120)\right]$$

Rotor $I^2R = 2(I_{FNL})^2\ (R_{f\ cold}) = 2(127a)^2\ (154)$

(183)	F&W	<u>FRICTION & WINDAGE LOSS</u> - Note: Write 0 on input sheet when computer is to calculate F & W. Insert actual value when known.

To ratio from test data, assume that F & W loss varies as the 5/2 power of the rotor diameter and as the 3/2 power of the RPM.

The formula below gives an approximate answer when test data is not available. For a more rigorous treatment use the information given in the rotor friction analysis appended to the thermal analysis section (Section C, Vol. 1).

$$F\&W = 2.52 \times 10^{-6} (d_r)^{2.5} (\ell_{NP} + \ell_1 + \ell_{g2}) (RPM)^{1.5}$$

$$= 2.52 \times 10^{-6} (11a)^{2.5} \left[(76)+(80a)+(78)\right] (7)^{1.5}$$

For gases or fluids other than standard air, the fluid density and viscosity must be considered. The formula given in the manual can be modified by the factors.

$$\left(\frac{(\rho)}{.0765}\right)^{.8} \left(\frac{u}{.0435}\right)^{.2}$$

where

ρ - density - Lbs FT^{-3}
μ - viscosity LBS FT^{-1} HR^{-1}
.0765 - density std. air
.0435 - viscosity std. air

(184)	W_{TNL}	STATOR TEETH LOSS -
(185)	W_C	STATOR CORE LOSS -
(186)	W_{NPL}	POLE FACE LOSS -
(187)	K_1	
(188)	K_2	
(189)	K_3	
(190)	K_4	
(191)	K_5	
(192)	K_6	
(193)	W_{DNL}	DAMPER LOSS -
(194)	I^2R	STATOR I^2R -

(195)	--	EDDY LOSS -
(196)	--	TOTAL LOSSES - at no load.

NOTE: The output sheet shows the next items to be: (Rating), (Rating + Losses), (% Losses), (% Efficiency). These items do not apply to the no load calculation since the rating is zero. Refer to Items (248), (249), (250), (251) for these calculations under load.

(197)	E_{NL}	LOAD CALCULATIONS - Run through sample at 100% load.

$$E_{NL} = (E_{PH}) + (I_{PH})(R_{PH})$$

$$= (4) + (8)(54)$$

(198)	e_d	
(198a)	θ	POWER FACTOR ANGLE

(199)	F_{gL1}	AIR GAP AMPERE TURNS UNDER LOAD - If there were no change in stator leakage flux from stator core to rotor skirt from the no load condition calculated in Item (96).
		$F_{gL1} = (e_d)(F'_g) = (198)(96)$
(200)	F_{TL1}	STATOR TEETH AMPERE TURN DROP AT FULL LOAD First approximation.
		$F_{TL1} = (F'_T)\left[1 + (P.F.)\right]$
		$= (97)\left[1 + (9)\right]$
(201)	F_{CL}	STATOR CORE AMPERE TURN DROP -
		The first approximation for the stator core density at no-load is used for the full-load calculation. The change in core density due to the change in ϕ_7 is not regarded as signifigant.
		$F_{CL} = F'_C$
		$= (98)$
(202)	ϕ_{7L1}	LEAKAGE FLUX FROM STATOR BACK-IRON TO ROTOR SKIRT - First approximation - in kilolines.
		$\phi_{7L1} = (P_7)\left[(F_{gL1}) + (F_{TL1}) + (F_{CL})\right] \times 10^{-3}$
		$= (86)\left[(199) + (200) + (201)\right] \times 10^{-3}$

(203) F'_{gL} TOTAL AIR GAP AMPERE TURNS AT FULL LOAD

$$F'_{gL} = F_{gL1} + \frac{(\phi_{7L1})(g_e) \times 10^3}{(A_g)\ 3.19} = (199) + \frac{(202)(69) \times 10^3}{(68)\ 3.19}$$

(204) ϕ_{TL1} THEORETICAL FLUX AT FULL LOAD - first approximation.

$$\phi_{TL1} = (\phi_{NL}) + \frac{(\phi_{7L1})}{(C_p)}$$

$$= (204) + \frac{(202)}{(73)}$$

Where $\phi_{NL} = (\phi_T) \left[\frac{(E_{NL})}{(E_{PH})}\right]$

$$= (88) \left(\frac{(197)}{(4)}\right)$$

(205) B_{TL} STATOR TOOTH DENSITY AT FULL LOAD ABOVE NORTH POLE

$$B_{TL} = \frac{(\phi_{TL1})}{(Q)(\ell_s)(b_{t\ 1/3})} = \frac{(204)}{(23)(17)(57a)}$$

(206) F_{TL} STATOR TOOTH AMPERE TURNS AT FULL LOAD

$$F_{TL} = (h_s) \left[\text{NI/inch at density } (B_{TL})\right] \left[1 + (P.F.)\right]$$

$$= (22) \left[\begin{array}{l}\text{Look up on stator magnetization curve} \\ \text{given in (18) at density (205)}\end{array}\right] \left[1 + (9)\right]$$

(207)	$\emptyset_{7L}$	LEAKAGE FLUX FROM STATOR BACK-IRON TO ROTOR SKIRT - second application.

$$\emptyset_{7L} = (P_7)\left[(F'_{gL1}) + (F_{TL}) + (F_{CL})\right] \times 10^{-3}$$

$$= (86)\left[(203) + (206) + (201)\right] \times 10^{-3}$$

(208)	$\emptyset_{TL}$	THEORETICAL FLUX AT F.L. - second approximation.

$$\emptyset_{TL} = (\emptyset_{NL}) + \frac{(\emptyset_{7L})}{(C_p)}$$

$$= (204) + \frac{(207)}{(73)}$$

(208a)	F_{gL}	

$$F_{gL} = F'_{gL} + \frac{(\emptyset_{7L})(g_e)\ 10^3}{3.19\ (A_g)}$$

$$= (203) + \frac{(207)(69)\ 10^3}{3.19\ (68)}$$

The next four items cover the flux leakages from pole to pole in the rotor. (In kilolines)

(209)	$\emptyset_{1L}$	$\emptyset_{1L} = (P_1)\left[2(F_{gL}) + 2(F_{TL}) + 2(F_{CL})\right] \times 10^{-3}$

$$= (80)\left[2(208a) + 2(206) + 2(201)\right] \times 10^{-3}$$

(210)	$\emptyset_{2L}$	$\emptyset_{2L} = (P_2)\left[2(F_{gL}) + 2(F_{TL}) + 2(F_{CL})\right] \times 10^{-3}$

$$= (81)\left[2(208a) + 2(206) + 2(201)\right] \times 10^{-3}$$

(211)	$\emptyset_{3L}$	$\emptyset_{3L} = (P_3)\left[2(F_{gL}) + 2(F_{TL}) + 2(F_{CL})\right] \times 10^{-3}$

$$= (82)\left[2(208a) + 2(206) + 2(201)\right] \times 10^{-3}$$

(212)	ϕ_{4L}	$\phi_{4L} = (P_4)\left[2(F_{gL}) + 2(F_{TL}) + 2(F_{CL})\right] \times 10^{-3}$ $= (83)\left[2(208a) + 2(206) + 2(201)\right] \times 10^{-3}$
(213)	ϕ_{PL}	FLUX PER POLE AT FULL LOAD For P.F. = 0.0 to .95 $\phi_{PL} = \phi_{PNL}\left[(e_d) - \frac{.93(X_{ad})}{100} \sin(\psi)\right]$ $= (213)\left[(198) - \frac{.93(131)}{100} \sin(198)\right]$ Where $\phi_{PNL} = \frac{(\phi_{TL})(C_P)}{(P)}$ $= \frac{(208)(73)}{(6)}$ For P.F. .95 to 1.0 $\phi_{PL} = (K_c)(\phi_{PNL})$ $= (9a)(213)$
(214)	ϕ_{SPFL}	SOUTH POLE FLUX AT FULL LOAD $\phi_{SPFL} = \frac{(\phi_{PL})}{2} + \frac{(\phi_{1L}) + (\phi_{2L}) + (\phi_{3L}) + (\phi_{4L})}{2(P)}$ $= \frac{(213)}{2} + \frac{(209) + (210) + (211) + (212)}{2(6)}$
(215)	B_{SPFL}	FLUX DENSITY IN SOUTH POLE AT FULL LOAD $B_{SPFL} = \frac{(\phi_{SPFL})}{(a_{SP})} = \frac{(214)}{(79a)}$

(216) F_{SPFL} SOUTH POLE AMPERE TURNS

When $b_{np}(\text{end}) = b_{np}(\text{mid})$

$$F_{SP\text{-}FL} = \frac{(\ell_{SP})}{3}\left[\text{NI/inch at density } (B_{SPFL})\right]$$

$$\frac{(76)}{3}\left[\begin{array}{l}\text{Look up on tube magnetization curve} \\ \text{given in (18) at density (215)}\end{array}\right]$$

When $b_{np}(\text{end}) \neq b_{np}(\text{mid})$

$$\frac{\ell_{SP}}{2}\left[\text{NI/inch at density } B_{SPFL}\right]$$

$$\frac{(76)}{2}\left[\begin{array}{l}\text{Look up on tube magnetization curve} \\ \text{given in (18) at density (215)}\end{array}\right]$$

(217) ϕ_{NPFL} NORTH POLE FLUX - First approximation without leakage ϕ_{5L}.

$$\phi_{NPFL} = (\phi_{PL}) + \frac{(\phi_{1L}) + (\phi_{2L}) + (\phi_{3L}) + (\phi_{4L})}{(P)}$$

$$(213) + \frac{(209) + (210) + (211) + (212)}{(6)}$$

(218) B'_{NPFL} NORTH POLE DENSITY AT FULL LOAD - first approximation.

$$B'_{NPFL} = \frac{(\phi_{NPFL})}{(a_{NP})} = \frac{(217)}{(79)}$$

(219) F'_{NPFL} NORTH POLE AMPERE TURN DROP - first approximation.

$$F'_{NPFL} = (h_{NP})\left[\text{NI/inch at density } (B'_{NPFL})\right]$$

$$(78)\left[\begin{array}{l}\text{Look up on N/P magnetization curve} \\ \text{given in (18) at density (218)}\end{array}\right]$$

(220)	ϕ_{6L}	LEAKAGE ACROSS FIELD COIL - from rotor shaft outer diameter to the inner surface of the rotor skirt.
		$\phi_{6L} = (P_6)\left[(F_{SPFL})+(F'_{NPFL})+2(F_{gL})+2(F_{TL})+2(F_{CL})\right] \times 10^{-3}$
		$= (85)\left[(216)+(219)+2(208a)+2(206)+2(201)\right] \times 10^{-3}$
(221)	ϕ_{SKFL}	FLUX AT THE SKIRT ENTRY EDGE OF AUXILIARY AIR GAP (g_2) - at full load.
		$\phi_{SKFL} = (\phi_{SPFL})\frac{(P)}{2} + \frac{(\phi_{6L})}{2}$
		$= (214)\frac{(6)}{2} + \frac{(220)}{2}$
(222)	B_{SKFL}	DENSITY AT THE SKIRT ENTRY EDGE OF AUXILIARY AIR GAP (g_2) - at full load.
		$B_{SKFL} = \frac{\phi_{SKFL}}{a_{SK}} = \frac{(221)}{(79b)}$
(223)	F_{SKFL}	ROTOR SKIRT AMPERE TURN DROP -
		$F_{SKFL} = (\ell_{SK})$ [NI/inch at density B_{SKFL}]
		= (78) [Look up on skirt magnetization curve given in (18) at density (222)]
		This value of ampere turns should be insignificant. The calculation of F_{SKFL} is in this program only for a check on a possible bottleneck.

(224)	B_{g2FL}	FLUX DENSITY IN AUXILIARY AIR GAP - at full load.
		$$B_{g2FL} = \frac{(\emptyset_{SKFL})}{(A_{g2})} = \frac{(221)}{(70)}$$
(225)	F_{g2FL}	AMPERE TURN DROP IN AUXILIARY GAP
		$$F_{g2FL} = \frac{(B_{g2FL})}{3.19} (g_2) \times 10^3$$
		$$= \frac{(224)}{3.19} (59a) \times 10^3$$
(226)	$\emptyset_{L5}$	LEAKAGE FLUX THROUGH FIELD COIL FROM NORTH POLE TO YOKE (y_2)
		$$\emptyset_{L5} = (P_5)\left[(F'_{NPFL})+2(F_{gL})+2(F_{TL})+2(F_c)+(F_{SPFL})+(F_{g2FL})\right] \times 10^{-3}$$
		$$= (84)\left[(219)+2(208a)+2(206)+2(201)+(216)+(225)\right] \times 10^{-3}$$
(227)	$\emptyset_{y2FL}$	FLUX IN COIL YOKE - At y_2 the smallest cross-section of yoke.
		$$\emptyset_{y2FL} = (\emptyset_{SKFL}) + \frac{(\emptyset_{L5})}{2}$$
		$$= (221) + \frac{(226)}{2}$$
(228)	B_{y2FL}	FLUX DENSITY IN COIL YOKE - At y_2 the smallest cross-section of yoke.
		$$B_{y2FL} = \frac{(\emptyset_{y2FL})}{(A_{y2})} = \frac{(227)}{(124)}$$

(229)	F_{y2FL}	AMPERE TURN DROP IN THE YOKE SECTION y_2. This value should be insignificant and the calculation is here to call attention to a possible saturation point. If the yoke section is made straight, of uniform thickness, all of the ampere turn drop will be in the lower half of the yoke.

$$F_{y2FL} = \frac{1}{3}(h_y)\left[NI/\text{inch at density } (B_{y2FL})\right]$$

$$= \frac{1}{3}(78)\left[NI/\text{inch at density } (228)\right]$$

(230)	B_{g3FL}	DENSITY OF AIR GAP g_3 - at full load.

$$B_{g3FL} = \frac{(\emptyset_{y2FL})}{(A_{g3})} = \frac{(227)}{(70a)}$$

(231)	F_{g3FL}	AMPERE TURN DROP ACROSS AIR GAP (g_3) - at full load. For stepped air gap i.e. when (59b) = 1.0 calculate as follows:

$$F_{g3FL} = \frac{B_{g3FL}\,(g_{3e})}{3.19} \times 10^3$$

$$= \frac{(230)(59f)}{3.19} \times 10^3$$

For tapered air gap i.e. when (59b) = 2 calculate as follows:

$$F_{g3FL} = \frac{B_{g3FL}\,(g_3)}{3.19} \times 10^3 = \frac{(230)(59c)}{3.19} \times 10^3$$

(232)	B_{y4FL}	FLUX DENSITY IN SHAFT AT ENTRY TO NORTH POLE
		$$B_{y4FL} = \frac{(\emptyset_{y2FL})}{(A_{y4})} = \frac{(227)}{(112)}$$
(233)	F_{y4FL}	AMPERE TURN DROP IN SHAFT
		$$F_{y4FL} = \frac{(\ell_{y4})}{2}\left[\text{NI/inch at density } (B_{y4FL})\right]$$ $$= \frac{(78)}{2}\left[\begin{array}{l}\text{Look up on shaft magnetization curve} \\ \text{given in (18) at density (232)}\end{array}\right]$$
(234)	B_{NPFL}	FLUX DENSITY IN NORTH POLE AT BASE
		$$B_{NPFL} = \frac{2(\emptyset_{y2FL})}{4(a_{NP})} = \frac{2(227)}{4(79)}$$
(235)	F_{NPFL}	NORTH POLE AMPERE TURN DROP
		$$F_{NPFL} = (h_{NP})\left[\text{NI/inch at density } (B_{NPFL})\right]$$ $$= (78)\left[\begin{array}{l}\text{Look up on north pole magnetization} \\ \text{curve given in (18) at density (234)}\end{array}\right]$$
(236)	F_{FL}	FULL LOAD AMPERE TURNS
		$$F_{FL} = 2(F_g)+2(F_T)+2(F_c)+(F_{SP})+(F_{NP})+(F_{SK})+(F_{g2})+(F_{y2})+(F_{g3FL}) +(F_{y4})$$ $$2(208)+2(206)+2(201)+(216)+(235)+(223)+(225)+(229)+(231)+(233)$$
(237)	I_{FFL}	FIELD CURRENT - at 100% load per coil
		$$I_{FFL} = \frac{(F_{FL})}{(N_F)} = \frac{(236)}{(146)}$$

(238)	E_{FFL}	FIELD VOLTS - at 100% load per coil. This calculation is made with hot field resistance at the expected temperature at 100% load. $E_{FFL} = (I_{FFL})(R_{F\ hot})$ $= (237)(155)$
(239)	S_{FL}	CURRENT DENSITY OF FIELD CONDUCTOR - at 100% load. Current Density $= \frac{(I_{FFL})}{(a_{cf})} = \frac{(237)}{(153)}$
(240)	--	Items (197) through (239) cover full load saturation calculations at 100% load. In order to calculate for any load other than 100% load, use the following procedure: Recalculate Item (197) as follows: $E_{NL} = E_{PH} + I_{PH}$ (Per Unit Load) R_{PH} $= (4) + (8)$ (Per Unit Load) (54) Recalculate Item (198) as follows: $= \tan^{-1}\left[\frac{\sin \Theta + (X_q)(\text{Per Unit Load})}{\cos \Theta}\right]$ $= \tan^{-1}\left[\frac{\sin(161) + (134)(\text{Per Unit Load})}{\cos(198)}\right]$ $e_d = \cos(\mathcal{E}) + (X_d)(\text{Per Unit Load}) \sin(\psi)$ $= \cos(\mathcal{E}) + (133)(\text{Per Unit Load}) \sin(240)$

Recalculate Item (213)

For P.F. = 0.0 to .95

$$\emptyset_{PL} = \emptyset_{PNL}\left[(e_d) - \frac{.93(X_{ad})(P.U.LOAD)}{100}\sin(\psi)\right]$$

$$= (213)\left[(240) - \frac{.93(131)(P.U.LOAD)}{100}\sin(240)\right]$$

With the changes made as shown in Item (240), recalculate Items (197) through (239) at the % load required using per unit load = $\frac{\%\ \text{load being used}}{100}$.

(241) I^2R_R <u>FIELD COIL I^2R</u> at 100% load - The copper loss in the field windings calculated with hot field resistance at expected temperature for 100% load condition. (for two coils).

Rotor $I^2R = 2(I_{FFL})^2(R_{F\ hot}) = 2(237)^2\ (155)$

(242) W_{TFL} <u>STATOR TEETH LOSS</u> at 100% load - The stator tooth loss under load increases over that of no load because of the parasitic fluxes caused by the ripple due to the rotor damper bar slot openings.

$$W_{TFL} = \left\{2\left[.4(X_d)\right]^{(ex)} + 1\right\} W_{TNL}$$

$$= \left\{2\left[.4(133)\right]^{(207)} + 1\right\} (184)$$

Where $(e_x) = 1.8$ if $\left[.4\frac{(X_d)}{100}\right] < 1.0$

$(e_x) = 2.0$ if $\left[.4\frac{(133)}{100}\right] > 1.0$

(243)	W_{PFL}	POLE FACE LOSS at 100% load

$$W_{PFL} = \left\{ \left[\frac{(K_{sc})(I_{PH}) \frac{(\%\ \text{Load})}{100} (n_s)}{(C)\ (F_{gL})} \right]^2 + 1 \right\} (W_{PNL}) + (W_{PHR})$$

$$= \left\{ \left[\frac{(243)\ (8)\ 1\ (30)}{(32)\ (208a)} \right]^2 + 1 \right\} (186) + (243)$$

(K_{sc}) is obtained from Graph 3

Where W_{PHR} = pole face harmonic loss

The pole face harmonic loss calculation is not included in this design manual; however, a space has been provided on the input sheet for the pole face harmonic loss if the designer calculates it by some other means. This calculated loss will be added to the normal pole face harmonic loss and the output will include both. When the calculated value of pole face harmonic loss is not available insert 0.0 on the input sheet. When the calculated value of pole face harmonic loss is available, insert the actual value on the input sheet in watts.

(244) W_{DFL} DAMPER LOSS at 100% load

$$W_{DFL} = \left\{ \left[\frac{(K_{SC})(I_{PH}) \frac{(\%\ \text{Load})}{100} (n_S)}{(C)(F_{gL})} \right]^2 + 1 \right\} (W_{DNL}) \times \frac{(\rho_D\ \text{hot})}{(\rho_D\ \text{cold})} + (W_{DHR})$$

$$= \left\{ \left[\frac{(244)\ (8)\ 1\ (30)}{(32)(166)} \right]^2 + 1 \right\} (193)\ \frac{(143)}{(141)} + (244)$$

(K_{SC}) is obtained from Graph 3

Where W_{DHR} = Damper bar harmonic loss

The damper bar harmonic loss calculation is not included in this design manual; however, a space has been provided on the input sheet for the damper bar harmonic loss if the designer calculates it by some other means. This calculated loss will be added to the normal damper harmonic loss and the output will include both. When the calculated value of the damper bar harmonic loss is not available, insert 0.0 on the input sheet. When the calculated value of damper harmonic loss is available, insert the actual value on the input sheet in watts.

(245)	I^2R	STATOR I^2R at 100% load -
(246)	--	EDDY LOSS -
(247)	--	TOTAL LOSSES at 100% load - sum of all losses at 100% load. Total Losses = (Field I^2R) + (F&W) + (Stator Teeth Loss) + (Stator Core Loss) + (Pole Face Loss) + (Damper Loss) + (Stator I^2R) + (Eddy Loss) = (241)+(183)+(242)+(185)+(243)+(244)+(245)+(246)
(248)	--	RATING IN KILOWATTS at 100% load
(249)	--	RATING & Σ LOSSES
(250)	--	% LOSSES
(251)	--	% EFFICIENCY

INPUT AUXILIARY DATA SHEET

Auxiliary information taken from the design manuals to be used in conjunction with input sheets for convenience.

A. All dimensions for lengths, widths, and diameters are to be given in inches.

B. Resistivity inputs, Items (141) and (151) are to be given in micro-ohm-inches.

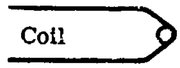
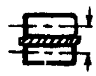
The following items along with an explanation of each are tabulated here for convenience. For complete explanation of each item number, refer to design manuals.

Item No.	Explanation
(9)	Power factor to be given in per unit. For example for 90% P. F., insert .90.
(9a)	Adjustment Factor - For P. F. $<$ .95 insert 1.0 For P. F. $>$ .95 insert 1.05
(10)	Optional Load Point -- Where load data output is required at a point other than those given as standard on the input sheet. Example: For load data output at 155% load, insert 1.55.
(14)	Number of radial ducts in stator.
(15)	Width of radial ducts used in Item (14).
(18)	Magnetization curve of material used to be submitted as defined in Item (18).
(19)	Watts/Lb. to be taken from a core loss curve at the density given in Item (20) (Stator).
(20)	Density in kilolines/in^2. This value must correspond to density used to pick Item (19) usually use 77.4 KL/in^2.
(21)	Type of slot - For open slot Type A, insert 1.0. For partially open slot Type B with constant slot width, insert 2.0. For partially open slot Type C with constant tooth width, insert 3.0. For round slot Type D, insert 4.0. For additional information, refer to figure adjacent to input sheet which shows a picture of each slot.
(22)	For stator slot dimension - for dimensions that do not apply to the slot insert 0.0. Use Table below as guide for input.

Symbol	Item	Slot Type 1	Slot Type 2	Slot Type 3	Slot Type 4
b_0	(22)	0.0	*	*	*
b_1		0.0	0.0	*	0.0
b_2		0.0	0.0	*	0.0
b_3		0.0	0.0	*	0.0
b_s		*	*	$\wp$	*
h_0		0.0	*	*	*
h_1		*	*	*	0.0
h_2		*	0.0	0.0	0.0
h_3		*	*	0.0	0.0
h_s		*	*	*	*
h_t		0.0	*	*	0.0
h_w		0.0	*	*	0.0

* = insert actual value.

$$\wp = b_s = \frac{b_1 + b_3}{2}$$

Item No.	Explanation
(28)	Type of winding - for wye connected winding insert 1.0. for delta connected winding insert 0.0.
(29)	Type of coil - for formed wound (rect. wire), insert 1.0. for random wound (round wire) insert 0.0.
(30)	Slots spanned - Example - for slot span of 1-10, insert 9.0.
(33)	For round wire insert diameter. For rectangular wire insert wire width.
(34)	Strands per conductor in depth only.
(34a)	Total strands per conductor in depth and width.
(35)	Diameter of coil head forming pin. Insert .25 for stator O.D. < 8 inches; Insert .50 for stator O.D. > 8 in. 
(37)	Use vertical height of strand for round wire, insert 0.0.
(38)	Distance between centerline of strands in depth. 
(39)	Stator strand thickness -- use narrowest dimension of the two dimensions given for a rectangular wire. For round wire insert 0.0.
(40)	Stator slot skew in inches.
(42a)	Phase belt angle - for 60^{o} phase belt, insert 60^{o}. for 120^{o} phase belt, insert 120^{o}.
(48)	See explanation of items (71), (72), (73), (74) and (75). Same applies here.
(87)	When no load saturation output data is required at various voltages, insert 1.0. When no load saturation information is not required, insert 0.0.
(137)	Damper bar thickness -- use damper bar slot height for rectangular bar. For round bar insert 0.0.
(138)	Number of damper bars per pole.
(140)	Damper bar pitch in inches.
(148)	For round wire insert diameter. For rectangular wire insert wire width.
(149)	For rectangular wire insert wire thickness. For round wire insert 0.0.
(187)	Pole face loss factor. For rotor lamination thickness .028 in. or less, insert 1.17. For rotor lamination thickness .029 in. to .063 in. insert 1.75. For rotor lamination thickness .064 in. to .125 insert 3.5. For solid rotor insert 7.0.
(71) (72) (73) (74) (75)	If the values of these constants are available, insert the actual number. If they are not available, insert 0.0 and the computer will calculate the values and record them on the output.

TWO OR SINGLE COIL OUTSIDE COIL LUNDELL

MODEL ________ EWO ________ DESIGN NO(1) ________

Section	Ref.	Symbol	Item	Value
PARAMETERS	(2)	KVA	GENERATOR KVA	
	(3)	E	LINE VOLTS	
	(4)	E_{ph}	PHASE VOLTS	
	(5)	m	PHASES	
	(5a)	f	FREQUENCY	
	(6)	p	POLES	
	(7)	RPM	RPM	
	(8)	I_{ph}	PHASE CURRENT	
	(9)	PF	POWER FACTOR	
	(9a)	K_c	ADJ. FACTOR	
	(10)		OPTIONAL LOAD POINT	
STATOR STACK	(11)	d	STATOR I.D.	
	(12)	D	STATOR O.D.	
	(13)		GROSS CORE LENGTH	
	(14)	n_v	NO. OF DUCTS	
	(15)	b_v	WIDTH OF DUCT	
	(16)	K_i	STACKING FACTOR STATOR	
	(19)	k	WATTS/LB.	
	(20)	S	DENSITY	
STATOR SLOT	(21)		TYPE OF SLOT	
	(22)	b_o	SLOT OPENING	
	(22)	b_1	SLOT WIDTH TOP	
	(22)	b_2		
	(22)	b_3		
	(22)	b_s	SLOT WIDTH	
	(22)	h_o		
	(22)	h_1		
	(22)	h_2		
	(22)	h_3		
	(22)	h_s	SLOT DEPTH	
	(22)	h_t		
	(22)	h_w		
	(23)	Q	NO. OF SLOTS	
STATOR WINDING	(28)		TYPE OF WDG.	
	(29)		TYPE OF COIL	
	(30)	n_s	CONDUCTORS/SLOT	
	(31)	y	SLOTS SPANNED	
	(32)	c	PARALLEL CIRCUITS	
	(33)		STRAND DIA. OR WIDTH	
	(34)	N_{st}	STRANDS/CONDUCTOR IN DEPTH	
	(34a)	N'_{st}	STRANDS/CONDUCTOR	
	(39)		STATOR STRAND T'KNS.	
	(35)	d_b	DIA. OF PIN	
	(36)	ℓ_{e2}	COIL EXT. STR. PORT	
	(37)	h_{st}	UNINS. STRD. HT.	
	(38)	h'_{st}	DIST. BTWN. C_L OF STD.	
	(42a)		PHASE BELT ANGLE	
	(40)	γ_{sk}	STATOR SLOT SKEW	
	(50)	X°C	STATOR TEMP °C	
	(51)	ρ_s	RES'TVY STA. COND. @ 20 °C	
GAP	(78)	ℓ_{g2}	LENGTH OF GAP (g2)	
	(78)	d_{g2}	DIAMETER AT GAP (g2)	
	(59)	g	MAIN AIR GAP	
	(59a)	g2	AUXILIARY AIR GAP	

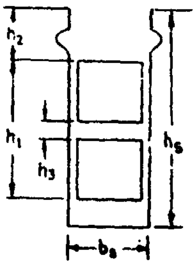
Section	Value	Item	Ref.	Symbol
CONSTANTS		FUND/MAX OF FLD FLUX	(71)	C_1
		WINDING CONSTANT	(72)	C_w
		POLE CONSTANT	(72)	C_p
		END EXTENSION ONE TURN	(48)	L_E
		DEMAGNETIZATION FACTOR	(74)	C_m
		CROSS MAGNETIZING FACTOR	(75)	C_q
		POLE EMBRACE	(77)	α
POLE		WIDTH OF POLE(NARROW END)	(76)	b_{p1}
		WIDTH OF POLE(WIDTH END)	(76)	b_{p2}
		POLE THICKNESS (NARROW END)	(76)	t_{p1}
		POLE THICKNESS (WIDE END)	(76)	t_{p2}
		POLE LENGTH	(76)	ℓ_p
		ROTOR DIAMETER	(11a)	d_r
		WEIGHT OF ROTOR IRON	(157)	(−)
		POLE FACE LOSS FACTOR	(187)	(K_1)
PERMEANCE		PERM OF LEAKAGE PATH 1	(80)	P_1
		PERM OF LEAKAGE PATH 2	(81)	P_2
		PERM OF LEAKAGE PATH 3	(82)	P_3
		PERM OF LEAKAGE PATH 4	(83)	P_4
		PERM OF LEAKAGE PAT	(84)	P
		PERM OF LEAKAGE PATH 7	(86)	P_7
		PERM OF LEAKAGE PATH	(86a)	P8
		DIA. OF END BELL AT SMALLEST SECT	(78)	d_{y2}
		THICKNESS OF END BELL " "	(78)	t_{y2}
		THICKNESS OF HOUSING SECTION	(78)	t_y
		LENGTH OF HOUSING SECTION	(78)	ℓ_y
		LENGTH OF PERM PATH 1	(80a)	ℓ_1
FIELD		NO. OF FIELD COILS	(146b)	N_{co}
		NO. OF FIELD TURNS/COIL	(146)	NF
		MEAN LENGTH OF FLD. TURN	(147)	ℓ_{tF}
		FLD. COND. DIA. OR WIDTH	(148)	
		FLD. COND. THICKNESS	(149)	
		FLD. TEMP IN °C	(150)	X_f °C
		RESISTIVITY OF FLD. COND. @ 20 °	(151)	ρ_f
		NO LOAD SAT.	(87)	
		FRICTION & WINDAGE	(183)	(F&W)
		SPECIAL PERMEANCE	(84a)	λ_7
MATR'L		STATOR LAM MATERIAL	(18)	
		POLE MATERIAL	(18)	
		YOKE MATERIAL (FLUX PLATE)	(18)	

STATOR SLOT	POLE
DAMPER SLOT	REMARKS

DESIGNER ________ DATE ________

M-01 REV. B

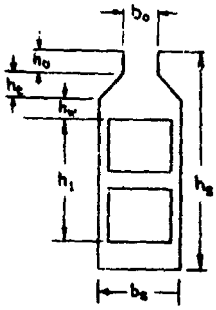
(a) Open Slots



TYPE 1

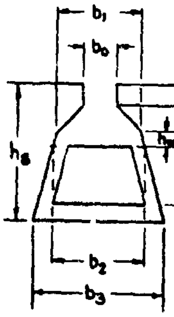
(Type 5 is an open slot with 1 conductor per slot)

(b) Constant Slot Width



TYPE 2

(c) Constant Tooth Width

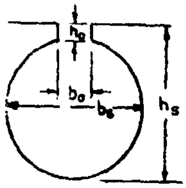


TYPE 3

b_s for type 3 is

$$b_s = \left(\frac{b_1 + b_3}{2}\right)$$

(d) Round Slots



TYPE 4

TWO OR
SINGLE

COIL OUTSIDE COIL LUNDELL

SUMMARY OF DESIGN CALCULATIONS - - - - - - - (OUTPUT)

MODEL NO. ________ EWO ________ DESIGN NO. ________

STATOR	(17) (ℓ_s)	SOLID CORE LENGTH			CARTER COEFFICIENT	(67) (K_s)		
	(24) (h_c)	DEPTH BELOW SLOT			EFFECTIVE AIR GAP	(69) (g_e)		
	(26) (τ_s)	SLOT PITCH			FUND/MAX OF FLD. FLUX	(71) (C_1)	CONSTANTS	
	(27) (τ_s1/3)	SLOT PITCH 1/3 DIST. UP			WINDING CONST.	(72) (C_w)		
	(42) (K_{sk})	SKEW FACTOR			POLE CONST.	(73) (C_p)		
	(43) (K_d)	DIST. FACTOR			END. EXT. ONE TURN	(48) (LE)		
	(44) (K_p)	PITCH FACTOR			DEMAGNETIZING FACTOR	(74) (C_M)		
	(45) (η_e)	EFF. CONDUCTORS			CROSS MAGNETIZING FACTOR	(75) (C_q)		
	(46) (a_c)	COND. AREA			AMP COND/IN	(128) (A)	REACTANCE	
	(47) (S_s)	CURRENT DENSITY (STA.)			REACTANCE FACTOR	(129) (X)		
	(49) (ℓ_t)	1/2 MEAN TURN LENGTH			LEAKAGE REACTANCE	(130) (X_ℓ)		
	(53) (R_{ph})	COLD STA. RES. @ 20° C			REACTANCE DIRECT AXIS	(131) (X_{ad})		
	(54) (R_{ph})	HOT STA. RES. @ X° C			REACTANCE QUAD. AXIS	(132) (X_{aq})		
	(55) (EF_{top})	EDDY FACTOR TOP			SYN REACT DIRECT AXIS	(133) (X_d)		
	(56) (EF_{bot})	EDDY FACTOR BOT			SYN REACT QUAD AXIS	(134) (X_q)		
	(62) (λ_i)	STATOR COND. PERM.			FIELD LEAKAGE REACT	(160) (X_f)		
	(63) (λ_e)	END PERM.			FIELD SELF INDUCTANCE	(161) (L_f)		
	(65) ( )	WT. OF STA COPPER			UNSAT. TRANS. REACT	(166) (X'_{du})		
	(66) ( )	WT. OF STA IRON			SAT. TRANS. REACT	(167) (X'_d)		
	(41) (τ_p)	POLE PITCH			SUB. TRANS REACT DIRECT AX.	(168) (X''_d)		
	(157) (–)	WT. OF ROTOR IRON			SUB. TRANS REACT QUAD AX.	(169) (X''_q)		
	(145) (V_r)	PERIPHERAL SPEED			NEG SEQUENCE REACT	(170) (X_2)		
FIELD	(153) (a_{cf})	FLD COND. AREA			ZERO SEQUENCE REACT	(172) (X_0)		
	(154) (R_f)	COLD FLD RES @ 20° C			OPEN CIR. TIME CONST.	(176) (T'_{do})	TIME CONST.	
	(155) (R_f)	HOT FLD RES @ X° C			ARM TIME CONST.	(177) (T_a)		
	(156) (–)	WT OF FLD COPPER			TRANS TIME CONST.	(178) (T'_d)		
PERMEANCE	(80) (P_1)	PERM OF LEAKAGE PATH 1			SUB. TRANS TIME CONST.	(179) (T''_d)		
	(81) (P_2)	PERM OF LEAKAGE PATH 2			TOTAL FLUX	(88) (Φ_T)	MAGNETIZATION	
	(82) (P_3)	PERM OF LEAKAGE PATH 3			FLUX PER POLE	(92) (Φ_p)		
	(83) (P_4)	PERM OF LEAKAGE PATH 4			GAP DENSITY (MAIN)	(95) (B_g)		
	(84) (P_5)	PERM OF LEAKAGE PATH 5			TOOTH DENSITY	(91) (B_t)		
	(86) (P_7)	PERM OF LEAKAGE PATH 7			CORE DENSITY	(94) (B_c)		
	(86a) (P_8)	PERM OF LEAKAGE PATH 8			TOOTH AMPERE TURNS	(97) (F_t)		
	(180) (FSC)	SHORT CIR NI			CORE AMPERE TURNS	(98) (F_c)		
	(181) (SCR)	SHORT CIR. RATIO			GAP AMPERE TURNS (MAIN)	(96) (F_g)		

PERCENT LOAD	0		100	150	200	OPTIONAL
(Φ_ℓ) (100a) LEAKAGE FLUX		($\Phi_{\ell\ell}$) (197a)				
(Φ_{p}) (102a) TOTAL FLUX/POLE		(Φ_{ptl}) (213a)				
(B_p) (103a) POLE DENSITY		(B_{pl}) (213b)				
(B_{g2}) (122) AUX. GAP DENSITY		(B_{g2L}) (224)				
(B_{y2}) (125) END BELL DENSITY		(B_{y2L}) (228)				
(B_y) (126a) HOUSING DENSITY		(B_{yl}) (229b)				
(F_{nl}) (127) TOTAL NI/COIL		(F_{fl}) (236)				
(I_{nl}) (127a) FIELD AMP./COIL		(I_{ffl}) (237)				
( ) (127c) CUR. DENSITY FIELD		(S_{fl}) (239)				
(E_{fnl}) (127b) FIELD VOLTS/COIL		(E_{ffl}) (238)				
(W_c) (185) STA CORE LOSS		(W_c) (185)				
(W_{tnl}) (184) STA TOOTH LOSS		(W_{tfl}) (242)				
(I^2R_s) (194) STATOR CU LOSS		(I^2R_1) (245)				
(–) (195) EDDY LOSS		(–) (246)				
(W_{pnl}) (186) POLE FACE LOSS		(W_{pfl}) (243)				
(I^2R_f) (182) FIELD COIL LOSS		(I^2R_{fl}) (241)				
(F&W) (183) F&W LOSS		(F&W) (183)				
(–) (196) TOTAL LOSSES		(–) (247)				
(–) (–) PERCENT EFF.		(–) (251)				

DESIGNER ________________ DATE ________

REV. A

TWO OR SINGLE COIL OUTSIDE COIL LUNDELL

NO LOAD SATURATION OUTPUT SHEET

ITEMS →	(3) (E) VOLTS	(91) B_t STA. TOOTH DENSITY	(97) F_t STA. TOOTH NI	(94) B_c STA. CORE DENSITY	(95) F_c STA. CORE NI	(96) F_g MAIN GAP DENS
% VOLTS ↓	(100a) ϕ_ℓ LEAKAGE FLUX	(102a) ϕPT TOTAL FLUX/POLE	(103a) B_p POLE DENSITY	(125) B_{y2} END BELL DENSITY	(126a) B_y HOUSING DENSITY	(127) F_{nl} TOTAL NI
__%						
90%						
100%						
110%						
120%						
130%						
140%						
150%						
160%						

REV.

TWO-COIL OUTSIDE-COIL LUNDELL

DESIGN COMPUTER MANUAL

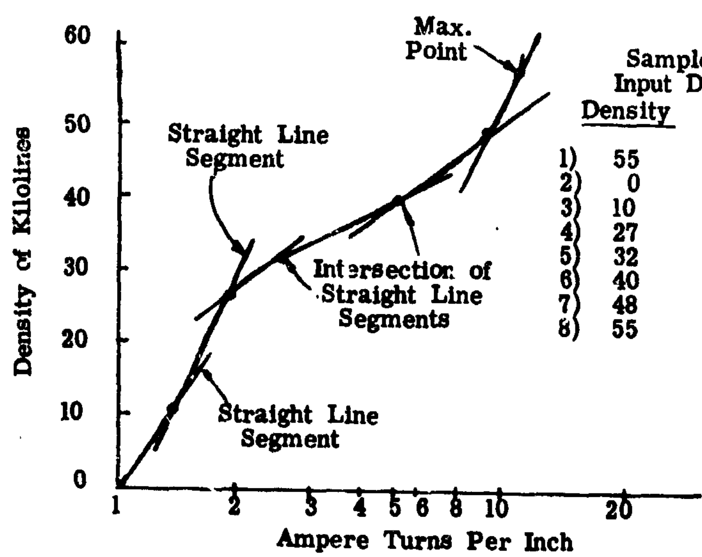
(1)	--	DESIGN NUMBER
(2)	KVA	GENERATOR KVA
(3)	E	LINE VOLTS
(4)	E_{PH}	PHASE VOLTS
(5)	m	PHASES
(5a)	f	FREQUENCY
(6)	P	POLES
(7)	RPM	SPEED
(8)	I_{PH}	PHASE CURRFNT
(9)	P. F.	POWER FACTOR
(9a)	K_c	ADJUSTMENT FACTOR
(10)	--	LOAD POINTS
(11)	d	STATOR PUNCHING I.D.
(11a)	d_r	ROTOR O.D.
(12)	D	PUNCHING O.D.
(13)	ℓ	GROSS STATOR CORE LENGTH
(14)	n_v	RADIAL DUCTS
(15)	b_v	RADIAL DUCT WIDTH
(16)	K_i	STACKING FACTOR
(17)	ℓ_s	SOLID CORE LENGTH

(18)

MATERIAL - This input is used in selecting the proper magnetization curves for stator, yoke, pole, when different materials are used. Separate spaces are provided on the input sheet for each section mentioned above. Where curves are available on card decks, used the proper identifying code. Where card decks are not available submit data in the following manner:

The magnetization curve must be available on semi-log paper. Typical curves are shown in this manual on Curves F15 & F16. Draw straight line segments through the curve starting with zero density. Record the coordinates of the points where the straight line segments intersect. Submit these coordinates as input data for the magnetization curve. The maximum density point must be submitted first.

Refer to Figure below for complete sample



Sample Input Data

	Density	NI
1)	55	Max.
2)	0	0
3)	10	1.5
4)	27	1.9
5)	32	2.5
6)	40	4.9
7)	48	9.0
8)	55	12.0

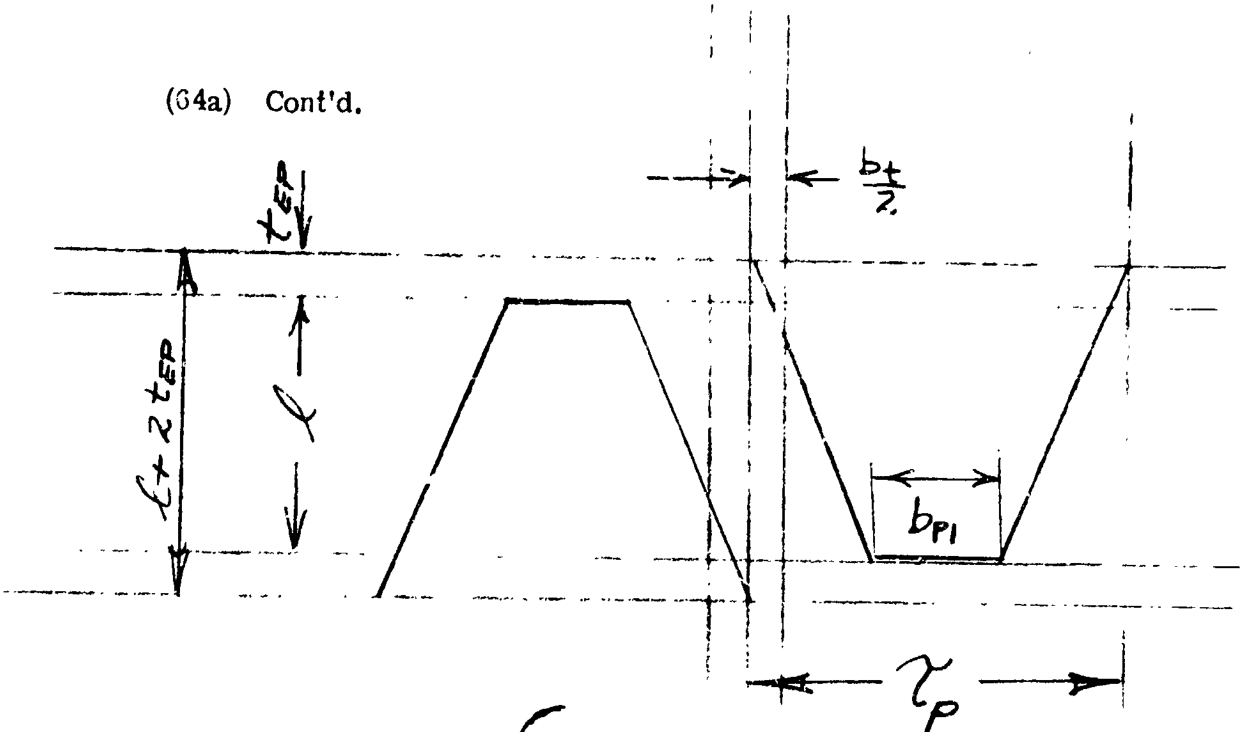
(19)	k	WATTS/LB
(20)	B	DENSITY
(21)		TYPE OF STATOR SLOT
(22)		ALL SLOT DIMENSIONS
(23)	Q	STATOR SLOTS
(24)	h_c	DEPTH BELOW SLOTS
(25)	q	SLOTS PER POLE PER PHASE
(26)	τ_s	STATOR SLOT PITCH
(27)	τ_s 1/3	STATOR SLOT PITCH
(28)	--	TYPE OF WINDING
(29)	--	TYPE OF COIL
(30)	n_s	CONDUCTORS PER SLOT
(31)	y	THROW
(31a)		PER UNIT OF POLE PITCH SPANNED
(32)	C	PARALLEL PATHS
(33)	--	STRAND DIA. OR WIDTH
(34)	N_{ST}	NUMBER OF STRANDS PER CONDUCTOR IN DEPTH
(34a)	N'_{ST}	NUMBER OF STRANDS PER CONDUCTOR
(35)	d_b	DIAMETER OF BENDER PIN
(36)	ℓ_{e2}	COIL EXTENSION BEYOND CORE
(37)	h_{ST}	HEIGHT OF UNINSULATED STRAND
(38)	h'_{ST}	DISTANCE BETWEEN CENTERLINES OF STRANDS IN DEPTH

(39)	--	STATOR COIL STRAND THICKNESS
(40)	τ_{SK}	SKEW
(41)	τ_P	POLE PITCH
(42)	K_{SK}	SKEW FACTOR
(42a)		PHASE BELT ANGLE
(43)	K_d	DISTRIBUTION FACTOR
(44)	K_p	PITCH FACTOR
(45)	n_e	TOTAL EFFECTIVE CONDUCTORS
(46)	a_c	CONDUCTOR AREA OF STATOR WINDING
(47)	S_S	CURRENT DENSITY
(48)	L_E	END EXTENSION LENGTH
(49)	ℓ_t	1/2 MEAN TURN
(50)	$X_s\,^{o}C$	STATOR TEMP °C
(51)	ρ_s	RESISTIVITY OF STATOR WINDING
(52)	ρ_S (hot)	RESISTIVITY OF STATOR WINDING
(53)	R_{SPH} (cold)	STATOR RESISTANCE/PHASE
(54)	R_{SPH} (hot)	STATOR RESISTANCE/PHASE
(55)	EF (top)	EDDY FACTOR TOP
(56)	EF (bot)	EDDY FACTOR BOTTOM

(57)	b_m	STATOR TOOTH WIDTH
(57a)	$b_{t\,1/3}$	STATOR TOOTH WIDTH
(58)	b_t	TOOTH WIDTH AT STATOR I.D. IN INCHES
(59)	g	MAIN AIR GAP IN INCHES
(59a)	g_2	AUXILIARY AIR GAP in inches
(60)	C_X	REDUCTION FACTOR
(61)	K_X	FACTOR TO ACCOUNT FOR DIFFERENCE in phase current in coil sides in same slot.
(62)	λ_i	CONDUCTOR PERMEANCE
(63)	K_E	LEAKAGE REACTIVE FACTOR
(64)	λ_E	END WINDING PERMEANCE
(64a)	λ_z	SPECIAL LEAKAGE PERMEANCE - For machines having a section of the pole that is approximately a full pole-pitch wide, an additional leakage permeance must be added to the slot and end-turn leakage permeances. This permeance is that of the leakage path from one pole into a tooth top and from tooth top back into the adjacent pole. The leakage

(64a)	Cont'd.	is similar to Zig Zag leakage and by increasing the stator leakage reactance, can reduce the output of the generator significantly. This same leakage can be used to purposely limit the output of the generator and make it current limited. The presence of this additional leakage can be good or bad depending upon what is wanted from the generator. The important thing is for the designer to be aware that it is there. In many cases, the designer should estimate the specific permeance λ_z since the pole base will be more or less than a full pole pitch wide and the following formula will not suffice.

(64a) Cont'd.



$$\lambda_z = (C_X)\frac{20}{(m)(q)}\left\{\frac{\text{area of pole over tooth when tooth is on centerline between poles}}{2\,\ell\, g}\right\}$$

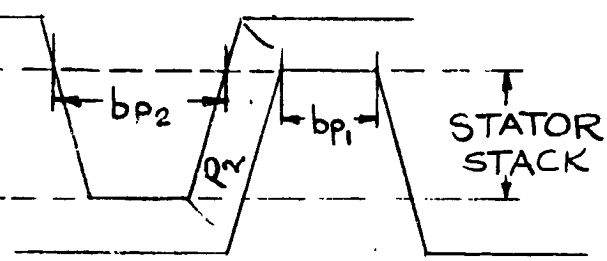
$$\lambda_z = (C_X)\frac{20}{(m)(q)}\left\{\frac{b_t\,(\tau_p - b_{p1})\,(\ell + 2\,t_{EP})\,\frac{(\tau_p - b_{p1})}{\tau_p}}{2\,\ell\,g}\right\}$$

(65)	--	WEIGHT OF COPPER
(66)	--	WEIGHT OF STATOR IRON
(67)	K_s	CARTER COEFFICIENT
(68)	A_g	MAIN AIR GAP AREA
(69)	g_e	EFFECTIVE AIR GAP
(70)	A_{g2}	AREA OF AUXILIARY AIR GAP
		$A_{g2} = \pi (d_{g2})(\ell_{g2}) = \pi (78)(78)$

(71)	C_1	THE RATIO OF MAXIMUM FUNDAMENTAL of the field form to the actual maximum of the field form.
(72)	C_W	WINDING CONSTANT
(73)	C_P	POLE CONSTANT
(74)	C_M	DEMAGNETIZING FACTOR
(75)	C_q	CROSS MAGNETIZING FACTOR
(76)		<u>POLE DIMENSION LOCATIONS</u>

b_{p2} = width of pole at edge of stator stack

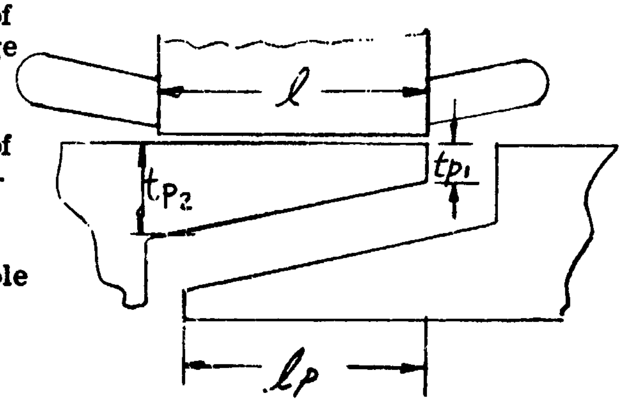
b_{p1} = pole width at terminus



t_{p2} = thickness of pole at edge of stator

t_{p1} = thickness of pole at terminus

ℓ_p = length of pole



(77) <u>POLE EMBRACE</u>

$$\alpha = \frac{b_{p1} + b_{p2}}{2(\tau_p)} = \frac{(76) + (76)}{2(41)}$$

(77a) -- Items immediately following deal with the calculation of rotor and stator leakage permeances.

Illustrations are included to help identify the permeance areas and to locate the flux leakage paths. The computer program will handle the calculation of permeances P_1, P_2, P_3 and P_4 either of two ways:

1. P_1 through P_4 can be calculated by the computer. For this case, insert 0.0 on the input sheet for P_1 through P_4.
2. P_1 through P_4 can be calculated by the designer. For this case, insert the actual calculated value on the input sheet for P_1 through P_4.

Permeance P_5 and P_7 must be calculated by the designer and the calculated value must be inserted on the input sheet. The computer will not calculate these two permeance values because of the various possible field coil locations.

Permeance calculations P_1 through P_7 are all based on the equation $P = \frac{\mu(\text{area})}{\ell}$

Where $\mu = 3.19$

Area = cross-sectional area perpendicular to the leakage flux.

ℓ = length of flux leakage path

Many of the equations used in this section are taken from Roter's "Electromagnetic Devices". Refer to the Appendix for the Roter's formulae.

(78)	--	ROTOR AND STATOR DIMENSIONS

ℓ_{g2} = axial length of gap (g2)

d_{y2} = diameter of yoke (end bell section) at narrowest section

d_{g2} = rotor diameter at auxiliary air gap

ℓ_y = half of the effective length of yoke

t_{y2} = thickness of end bell section of yoke

t_y = thickness of housing section of yoke

d_r = rotor diameter at main air gap

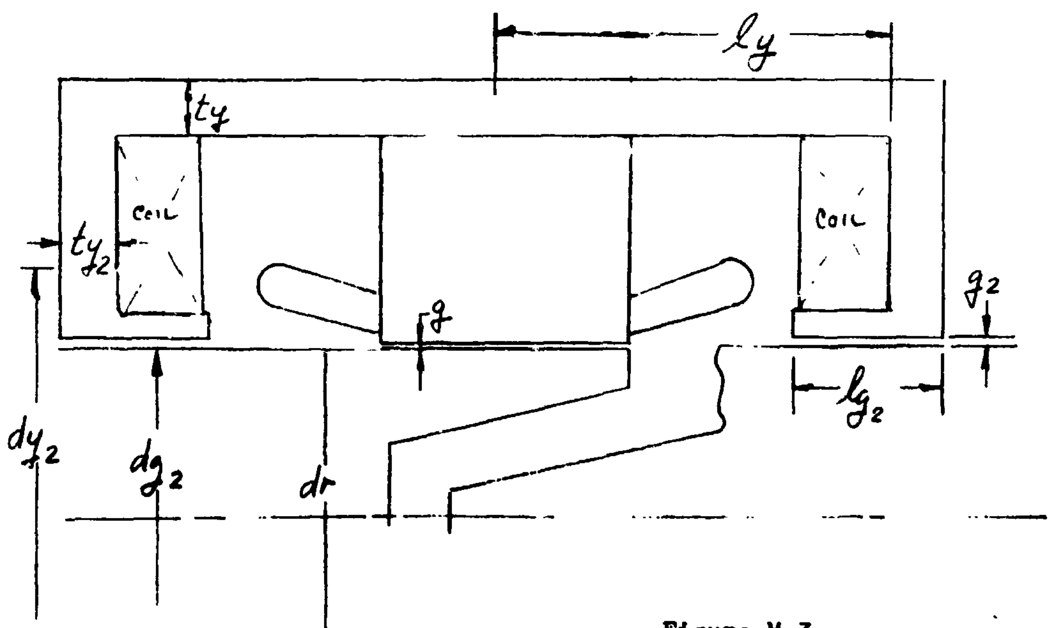


Figure M-3

(79)	a_p	POLE AREA - The effective cross-sectional area of the pole. $a_p = (b_{p2})(t_{p2}) = (76)(76)$
(80)	P_1	POLE HEAD END LEAKAGE - This can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure M-4 for location. $P_1 = \frac{3.19\ (b_{p1})(t_{p1})}{(\ell_1)} = \frac{3.19\ (76)(76)}{(80a)}$
(80a)	ℓ_1	ℓ_1 = length of permeance path P_1 and must be obtained from design layout. Must be given on input sheet when P_1 = 0.0.
(81)	P_2	POLE HEAD SIDE LEAKAGE - This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure M-5 for location. $P_2 = \frac{3.19\left\{(\ell_p)\left[\frac{(t_{p2}) + (t_{p1})}{2}\right]\right\}}{(\ell_2)} = \frac{3.19\left\{(76)\left[\frac{(76) + (76)}{2}\right]\right\}}{(81a)}$
(81a)	ℓ_2	LENGTH OF PERMEANCE PATH P_2 IN INCHES $\ell_2 = (\tau_p) - \left[\frac{(b_{p1}) + (b_{p2})}{2}\right] = (41) - \left[\frac{(76) + (76)}{2}\right]$

(82)	P_3	POLE BODY END LEAKAGE - This ~~input can be either~~ 0.0 or the actual value if available. Refer to Item (86) for explanation. See Figure M6 for location. $$P_3 = \frac{6.28}{\pi}\left[3\ \frac{(b_{p1}) + (b_{p2})}{4}\right] \ln \frac{(r_3)}{(r_4)}$$ $$= \frac{6.28}{\pi}\left[3\ \frac{(76) + (76)}{4}\right] \ln \frac{(82b)}{(82c)}$$
(82b)	r_4	$r_4 = \ell_1 = (80a) =$ length of permeance path P_1
(82c)	r_3	$r_3 = (\ell_1) + \frac{(\ell)}{2} = (80a) + \frac{(13)}{2}$
(83)	P_4	POLE BODY SIDE LEAKAGE - This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure M7 for location. When (6) > 4 $$P_4 = \frac{3.19\ (\ell_p)}{\pi} \ln \left[1 + \frac{(b_{p1}) + (b_{p2})}{2\ (Z)}\right]$$ $$= \frac{3.19(76)}{\pi} \ln \left[1 + \frac{(76) + (76)}{2(83)}\right]$$ Where $Z = (T_p) - \left[\frac{(b_{p1}) + (b_{p2})}{2}\right] = (41) - \left[\frac{(76) + (76)}{2}\right]$

When (6) $\leq$ 4

$$P_4 = \frac{3.19\ (\ell_p)}{\pi}\ \frac{3}{2}\ \ell n \left[1 + \frac{(b_{p1}) + (b_{p2})}{2\ Z}\right]$$

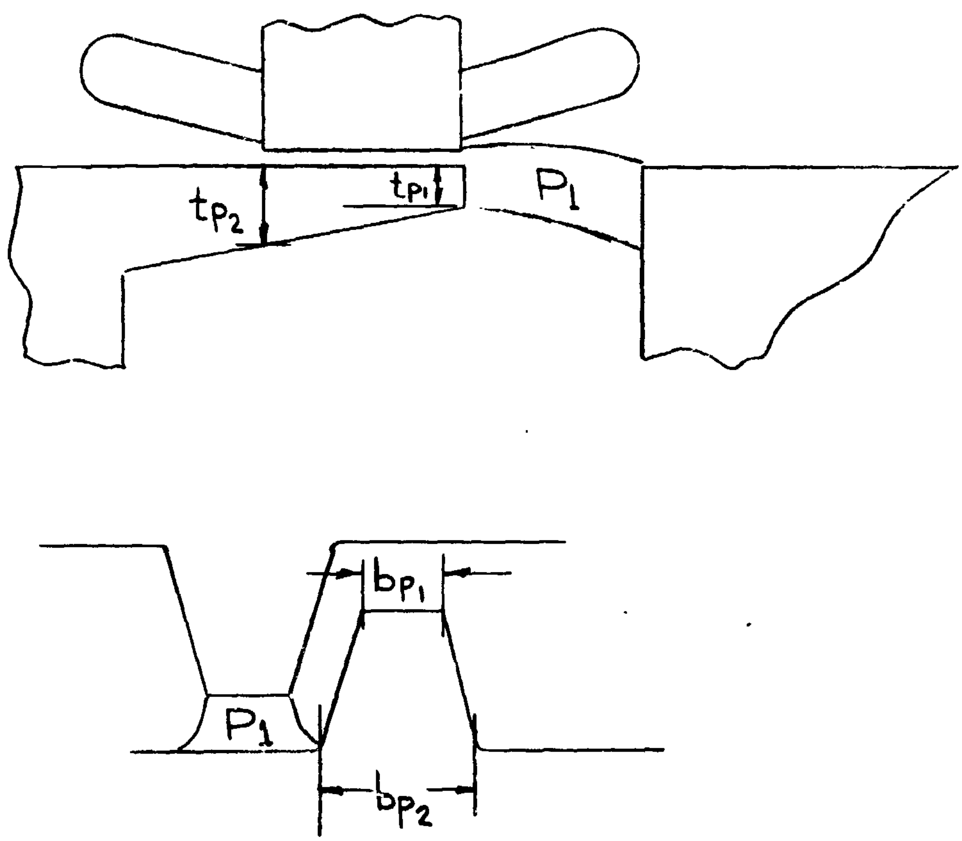
$$= \frac{3.19\ (76)}{\pi}\ \frac{3}{2}\ \ell n \left[1 + \frac{(76) + (76)}{2\,(83)}\right]$$

(84) P_5 COIL LEAKAGE PERMEANCE PER COIL - This permeance must be calculated by the designer and the calculated value must be inserted on the input sheet. Refer to Fig. M-8 & M-9, which show the location of the coil. This value is to be given on a per coil basis. Refer to the appendix for permeance formulae.

(86) P_7 STATOR TO FRAME AND ROTOR LEAKAGE PERMEANCE - Refer to Fig. M-8 & M-9 for location. This permeance is actually broken down into three parts: P_{71} leakage to yoke; P_{72} leakage to shaft; P_{73} leakage to rotor pole. In this design manual, the three permeances are added and treated as a single leakage. The same condition applies to P_7 and P_5. The designer must calculate P_7 and insert the calculated value on the input sheet. Refer to the appendix for formulae.

(86a)	P_8	<u>FLUX PLATE TO FLUX PLATE LEAKAGE PERMEANCE</u>

This permeance must be calculated by the designer and the value must be inserted on the input sheet. Location per Figure M-8.



LEAKAGE PERMEANCE P_1

Figure M-4

P_2 POLE HEAD SIDE LEAKAGE

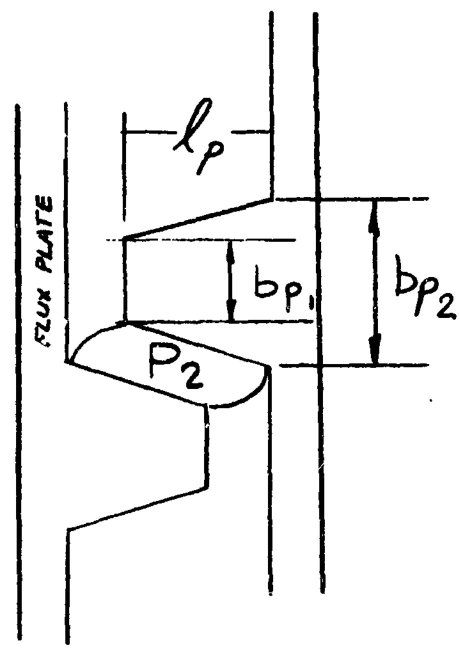


Figure M-5

P_3 POLE BODY END LEAKAGE

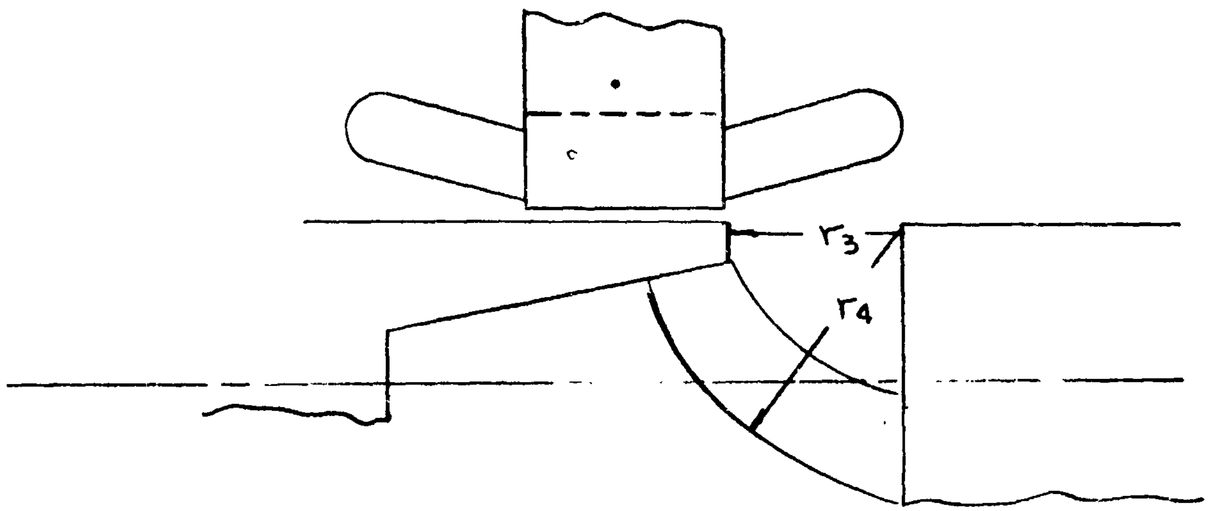


Figure M-6

P_4 POLE BODY LE/

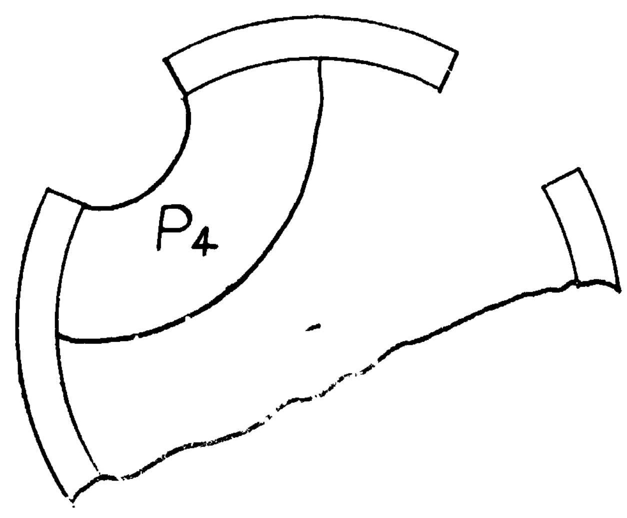
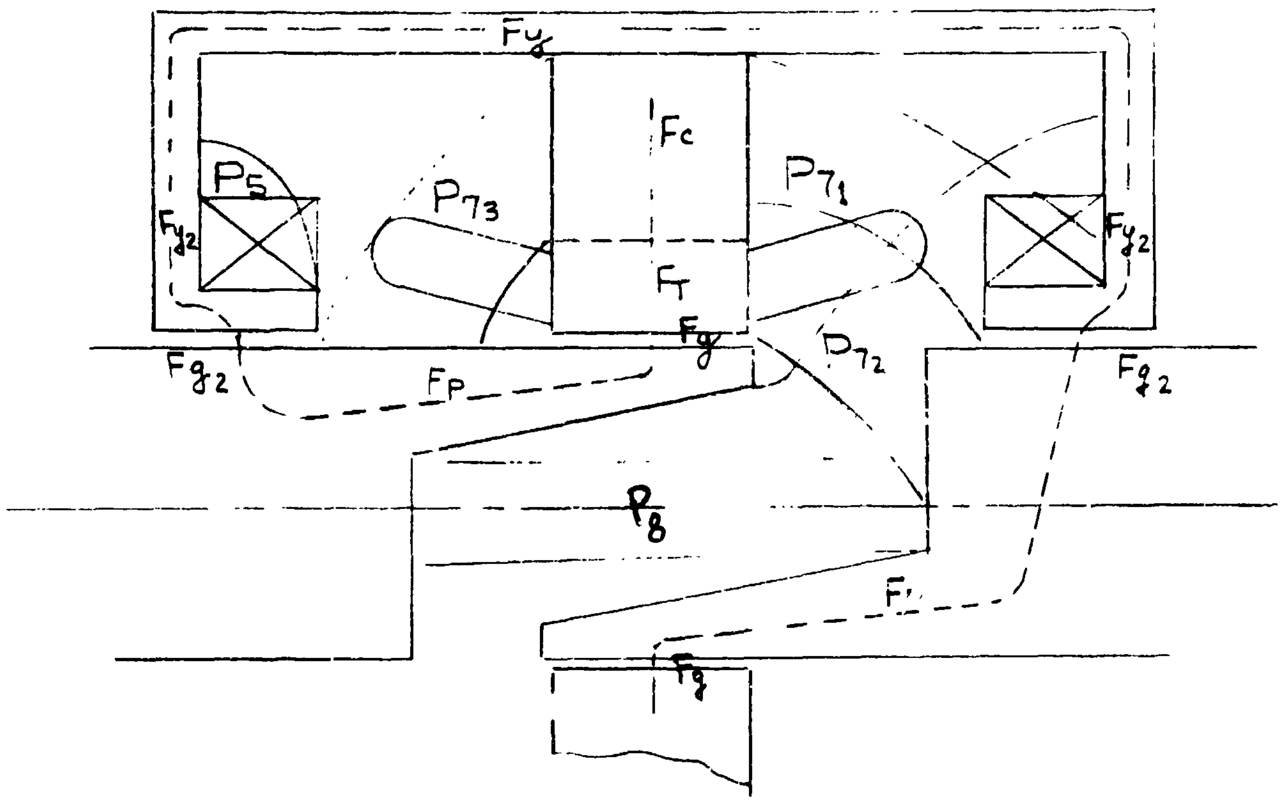


Figure M-7

FLUX CIRCUIT FOR THE TWO-COIL, OUTSIDE-COIL LUNDELL



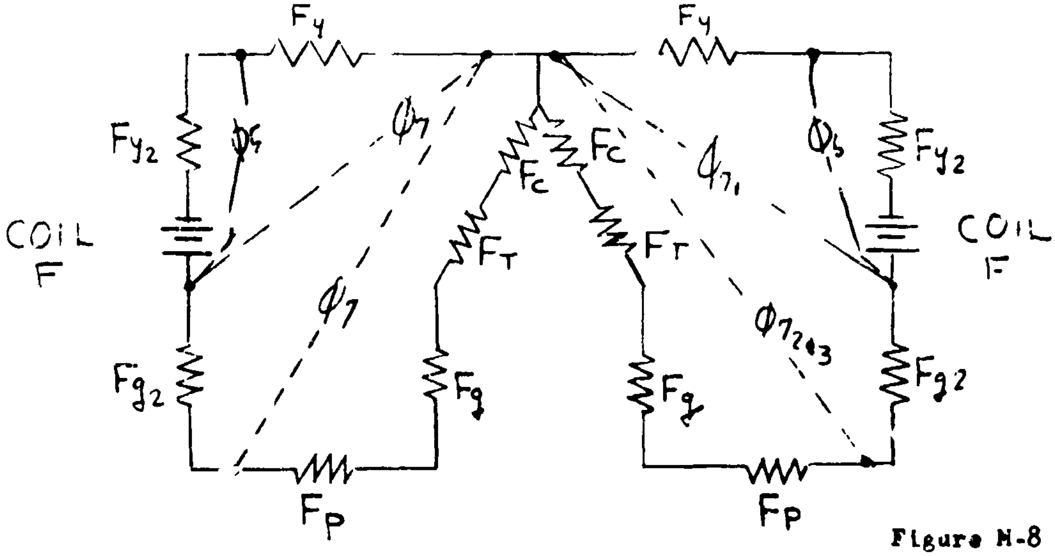
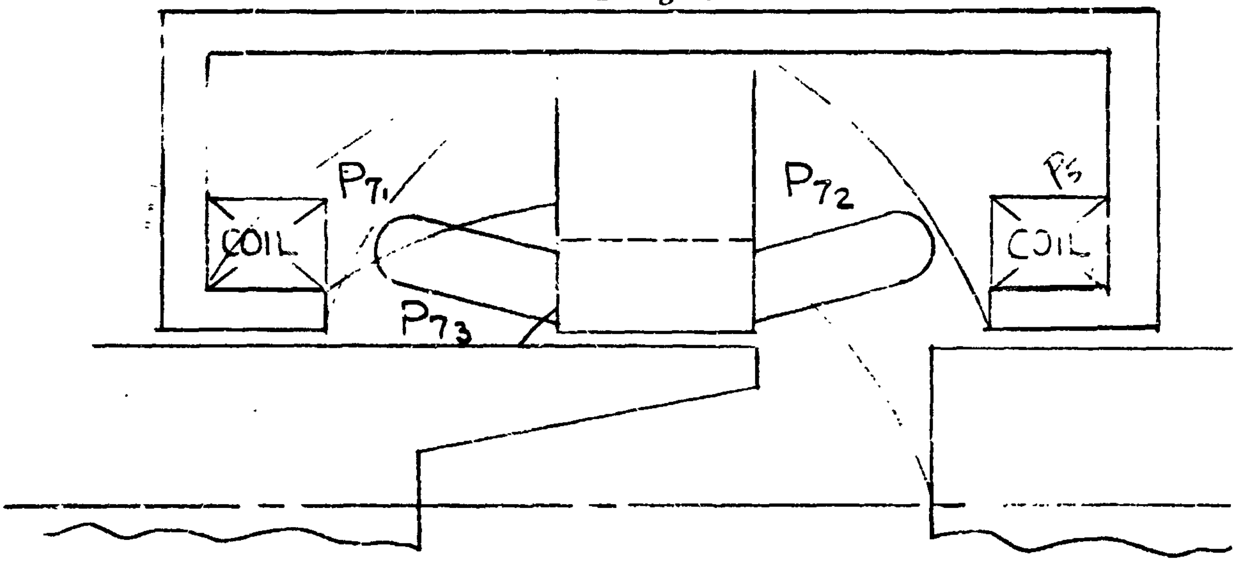


Figure M-8

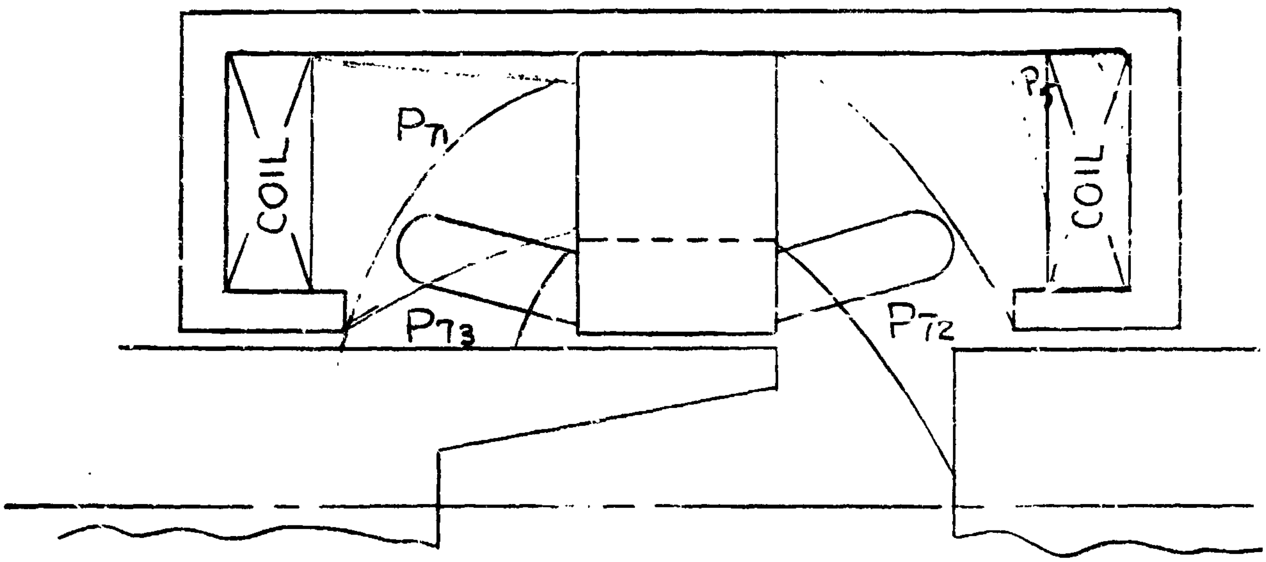
P_5 = Coil Leakage Permeance
P_7 = Stator Leakage Permeances

Figure M-9

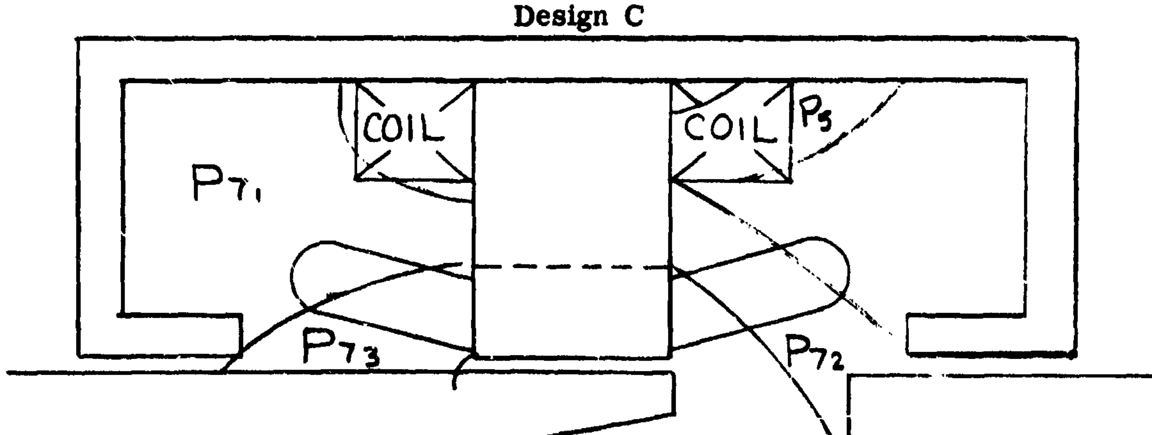
Design A



Design B



Design C



(87)	--	The next set of calculations deals with the no load saturation. The equations in this section can be used to calculate the no load saturation for any voltage. When the no load saturation data is required at various voltages insert 1. on the input sheet for "No Load Sat.". The computer will then calculate the no load saturation curve at 80, 90, 100, 110, 120, 130, 140, 150, and 160% of rated volts. When the complete saturation data is not necessary, insert 0. on the input sheet and the computer will calculate the 100% volt data.
(88)	ϕ_T	TOTAL FLUX IN KILOLINES
(91)	B_t	TOOTH DENSITY
(92)	ϕ_P	FLUX PER POLE
(94)	B_c	CORE DENSITY
(95)	B_g	GAP DENSITY
(96)	F_g	AIR GAP AMPERE TURNS
(97)	F_T	STATOR TOOTH AMPERE TURNS
(98)	F_c	STATOR CORE AMPERE TURNS

(98a)	F_s	STATOR AMPERE TURNS
(99)	ϕ_7	STATOR TO YOKE LEAKAGE FLUX - The leakage flux from the stator to the yoke.

$$\phi_7 = \left[(F_c) + (F_T) + (F_g) + (F_p)\right](P_7)\,10^{-3}$$

$$= \left[(98) + (97) + (96) + (104a)\right](86)\,10^{-3}$$

The items to follow are to be calculated for variable loads. These calculations will then be repeated for 100% load.

(100a)	ϕ_ℓ	ROTOR LEAKAGE FLUX - at no load

$$\phi_\ell = (P)\left[2(F_g) + 2(F_T) + (F_c)\right]\left[(P_1) + (P_2) + (P_3) + (P_4)\right] \times 10^{-3}$$

$$= (6)\left[2(96) + 2(97) + (98)\right]\left[(80) + (81) + (82) + (83)\right] \times 10^{-3}$$

(102a)	ϕ_{PT}	TOTAL FLUX PER POLE - at no load

$$\phi_{PT} = (\phi_P) + \frac{2(\phi_\ell)}{(P)} = (92) + \frac{2(100a)}{(6)}$$

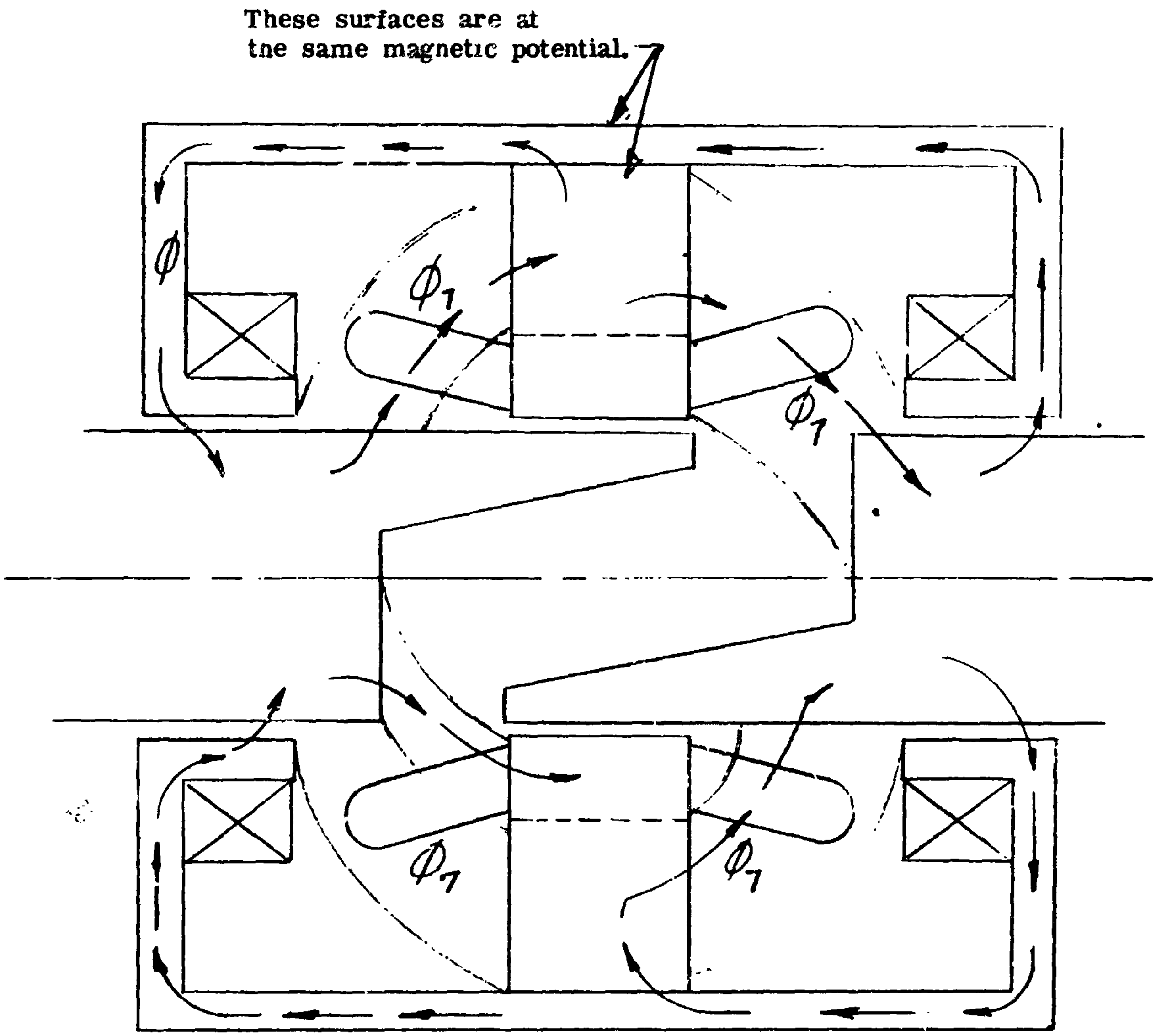
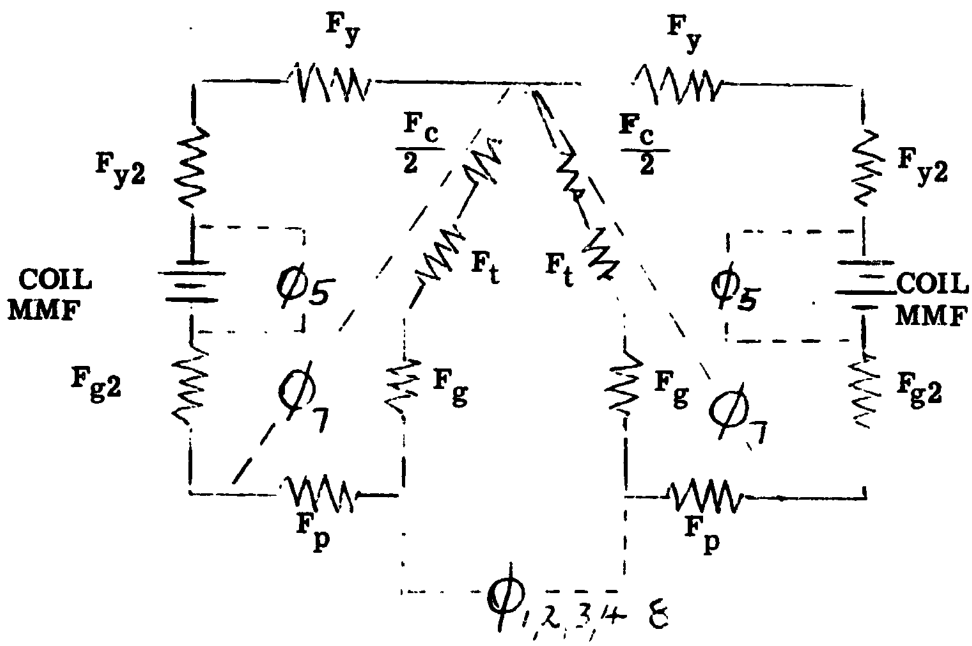


Figure M-10

The sketch above shows the leakage flux ϕ_7 leaking from the stator to the rotor. In a 2-pole generator of this configuration, the leakage flux, ϕ_7 can cause a rotating couple on the rotor.



Schematic representatio~ of the flux circuit of a two, outside-coil Lundell, a-c generator. The mmf drops in the circuit are shown by solid lines. The flux leakage paths are shown by dashed lines.

Figure M-11

(103a)	B_P	POLE DENSITY - The apparent flux density at the base of the pole. Note that no provision is made in this manual for calculating the density in the flux plate. It is, therefore, important to remember not to restrict the flux area through this section. $$B_P = \frac{(\phi_{PT})}{(a_P)} = \frac{(102a)}{(79)} \text{ Kilolines/in}^2$$
(103b)	ϕ_8	FLUX PLATE TO FLUX PLATE LEAKAGE FLUX (KILOLINES) $$\phi_8 = (P_8)\left[2(F_g) + 2(E_T) + (F_c)\right] \times 10^{-3}$$ $$= (86a)\left[2(96) + 2(97) + (98)\right] \times 10^{-3}$$
(104a)	F_P	POLE AMPERE TURNS - at no load. The ampere turns per pole required to force the flux through the pole and spider at no load rated voltage. The no load pole ampere turns per pole are calculated as the product of (ℓ_P) times the NI per inch at the density (B_P). Use magnetization curve submitted per item (18) for rotor. $$F_P = (\ell_P)\left[\text{NI/in @ density } (B_P)\right]$$ $$= (76)\left[\text{Look up on rotor magnetization curve given in (18) @ density (103a)}\right]$$
(108)	ϕ_{g2}	AUXILIARY GAP (g_2) flux in kilolines. $$\phi_{g2} = \phi_{PT}\frac{(P)}{2} + (\phi_7) + (\phi_8)$$ $$= (102a)\frac{(6)}{2} + (99) + (103b)$$

(118) ϕ_5 **COIL LEAKAGE FLUX PER COIL (Kilolines)**

$$\phi_5 = (P_5)\left[(F_{g2}) + F_y + (F_P) + (F_g) + (F_T) + (F_c)\right] \times 10^{-3}$$

$$\phi_5 = (84)\left[(123) + (126b) + (104a) \quad (96) + (97) + (98)\right] \times 10^{-3}$$

(122) B_{g2} **AUXILIARY GAP (g_2) FLUX DENSITY**

$$B_{g2} = \frac{(\phi_{g2})}{(A_{g2})} = \frac{(108)}{(70)}$$

(123) F_{g2} **AUXILIARY AIR GAP AMPERE TURNS**

$$F_{g2} = \frac{(B_{g2})}{3.19}(g_2) \times 10^3 = \frac{(122)}{3.19}(59a) \times 10^3$$

(124) A_{y2} **AREA OF END BELL SECTION OF YOKE AT SMALLEST SECTION**

$$A_{y2} = \pi(d_{y2})(t_{y2}) = \pi(78)(78)$$

(124a) A_y **AREA OF HOUSING PORTION OF YOKE**

$$A_y = \pi\left[(D) + (t_y)\right](t_y)$$

$$= \pi\left[(12) + (78)\right](78)$$

(125) B_{y2} **FLUX DENSITY IN END BELL SECTION OF YOKE @ N. L.**

at narrowest part

$$B_{y2} = \frac{(\phi_{g2} + \phi_5}{(A_{y2})} = \frac{(108) + (118)}{(124)}$$

(126)	F_{y2}	**AMPERE TURN DROP IN END BELL SECTION OF YOKE @ N. L.**
		$F_{y2} = \left[\frac{(D)-(d_{y2})}{6}\right]\left[\text{NI/inch @ } (B_{y2})\right]$
		$= \left[\frac{(12)-(78)}{6}\right]\left[\text{Look up on yoke magnetization curve @ density (125)}\right]$
(126a)	B_y	**DENSITY IN HOUSING SECTION OF YOKE @ N. L.**
		$B_y = \frac{(\emptyset_{g2})}{A_y} = \frac{(108)}{(124a)}$
(126b)	F_y	**AMPERE TURN DROP IN HOUSING SECTION OF YOKE**
		using 1/2 total length of housing
		$F_y = (\ell_y)\left[\text{NI/inch at density } (B_y)\right]$
		$= (78)\left[\text{Look up on yoke magnetization curve @ density (126a)}\right]$
(127)	F_{NL}	**TOTAL AMPERE TURN DROP @ N. L.**
		$F_{NL} = 2\left[(F_y)+(F_{y2})+(F_{g2})+(F_P)+(F_g)+(F_T)+\frac{(F_c)}{2}\right]$
		$= 2\left[(126b)+(126)+(123)+(104a)+(96)+(97)+\frac{(98)}{2}\right]$
(127a)	I_{FNL}	**FIELD CURRENT** - at no load
		$I_{FNL} = \frac{(F_{NL})}{(N_F)(N_{CO})} = \frac{(127)}{(146)(146a)}$

(127b)	E_F	FIELD VOLTS - at no load. This calculation is made with cold field resistance at 20° C for no load condition. $$E_F = (I_{FNL}) / (R_{f\ cold})(N_{CO}) = 127a / (154)(146a)$$
(127c)	S_F	CURRENT DENSITY - at no load.
(128)	A	AMPERE CONDUCTORS per inch
(129)	X	REACTANCE FACTOR
(130)	X_ℓ	LEAKAGE REACTANCE - in per cent, $$X_\ell = X\left[\lambda_i + \lambda_E + \lambda_z\right]$$ $$= (129)\left[(62) + (64) + (64a)\right]$$ λ_z is explained under item (64a) and should be zero in most cases.
(131)	X_{ad}	REACTANCE - direct axis - This is the fictitious reactance due to armature reaction in the direct axis (in per cent). $$X_{ad} = \frac{.9(n_e)(I_{PH})(C_m)(K_d) \times 100}{2(P)\ (F_g + F_{g2})} = \frac{.9(45)(8)(74)(43) \times 100}{2(6)\left[(96) + (123)\right]}$$

(132	X_{aq}	<u>REACTANCE</u> - quadrature axis - This is the fictitious reactance due to armature reaction in the quadrature axis (in per cent). $$X_{aq} = \frac{(C_q)(X_{ad})}{(C_m)(C_1)} = \frac{(75)(131)}{(74)(71)}$$
(133)	X_d	<u>SYNCHRONOUS REACTANCE</u> - direct axis - (%)

(134)	X_q	SYNCHRONOUS REACTANCE - quadrature axis (%)
(145)	V_r	PERIPHERAL SPEED
(146)	N_F	NUMBER OF FIELD TURNS per coil
(146a)	N_{CO}	NUMBER OF FIELD COILS - One basic computer program is used for the single-coil and two-coil Lundell generators. This item is used in the computer program as a code for distinguishing one from the other. Coils are connected in series.
(147)	ℓ_{tf}	MEAN LENGTH OF FIELD TURN - inches
(148)	--	FIELD CONDUCTOR DIA OR WIDTH in inches
(149)	--	FIELD CONDUCTOR THICKNESS in inches - Set this item = 0. for round conductor.
(150)	$X_f\,^{\circ}C$	FIELD TEMP IN $^{\circ}C$
(151)	ρ_f	RESISTIVITY of field conductor
(152)	ρ_f (hot)	RESISTIVITY of field conductor
(153)	a_{cf}	CONDUCTOR AREA OF FIELD WDG
(154)	R_f (cold)	COLD FIELD RESISTANCE @ 20°C per coil
		$R_f\ (\text{cold}) = (\rho_f)\dfrac{(N_f)\ (\ell_{tf}) \times 10^{-6}}{(a_{cf})} = (151)\dfrac{(146)\ (147) \times 10^{-6}}{(153)}$

(155)	R_f (hot)	<u>HOT FIELD RESISTANCE</u> - Calculated at $X_f{}^oC$ (103) per coil.
		$R_{f\ (hot)} = (\rho_{f\ hot}) \dfrac{(N_f)\ (\ell_{tf}) \times 10^{-6}}{(a_{cf})} = (152)\ \dfrac{(146)\ (147) \times 10^{-6}}{(153)}$
(156)	--	<u>WEIGHT OF FIELD COIL</u> in lbs - per coil
		#'s of copper $= .321 (N_f)(\ell_{tf})(a_{cf})$
		$= .321 (146)(147)(153)$
		NOTE: This answer is given in lbs. based on density of copper. If any other material is used, the answer on output sheet can be converted by the designer by multiplying by the ratio of densities.
(157)	--	<u>WEIGHT OF ROTOR IRON</u> - Because of the large number of different pole shapes, one standard formula cannot be used for calculating rotor iron weight. Therefore the computer will not calculate rotor iron weight. The space is allowed on the input sheet for record purposes only. By inserting 0. in the space allowed for rotor iron weight, the computer will show "0" on the output sheet. If the rotor iron weight is available and inserted on input sheet, then the output sheet will show this same weight on the output sheet.

(160)	X_F	**THE EFFECTIVE FIELD LEAKAGE REACTANCE** - The reactance which added to the stator leakage reactance gives the transient reactance X'_{du}.

When unit fundamental armature ampere turns are suddenly applied on the direct axis, an initial field current (I_f) will be induced. The value of this initial field current will be just enough to make the net flux interlinking the field because of the field current and the armature current zero. The field ampere turns

$$X_F = X_{ad}\left[1 - \frac{\frac{C_1}{C_m}}{2C_p + \frac{4}{\pi}\,\frac{\lambda_F}{\lambda_a}}\right]$$

$$X_F = (131)\left[1 - \frac{\frac{(71)}{(74)}}{2(73) + \frac{4}{\pi}\,\frac{(160)}{(160)}}\right]$$

$$\lambda_a = \frac{6.38(d)}{(P)g_e'} = \frac{6.38(11)}{(6)\,(160)}$$

$$g'_e = g_e\left[\frac{F_g - F_{g2}}{F_g}\right] = (69)\left[\frac{(96) - (123)}{(96)}\right]$$

$$\lambda_F = \frac{P_e}{\ell} = \frac{(160a)}{(13)}$$

(160a)	P_e	FIELD LEAKAGE PERMEANCE
		$P_e = P\left[P_1 + P_2 + P_3 + P_4\right] + P_5 + P_8$
		$= (6)\left[(80) + (81) + (82) + (83)\right] + (84) + (86a)$
(161)	L_f	FIELD SELF-INDUCTANCE
		$L_f = (N_F)^2\ (P_e)\ (N_{CO}) \times 10^{-8}$
		$= (146)^2\ (160a)\ (146a) \times 10^{-8}$
(166)	X'_{du}	UNSATURATED TRANSIENT REACTANCE
(167)	X'_d	SATURATED TRANSIENT REACTANCE
(168)	X''_d	SUBTRANSIENT REACTANCE in direct axis
(169)	X''_q	SUBTRANSIENT REACTANCE in quadrature axis
(170)	X_2	NEGATIVE SEQUENCE REACTANCE
(172)	X_0	ZERO SEQUENCE REACTANCE
(173)	K_{xo}	
(174)	K_{x1}	
(175)	λ_{Bo}	

(176)	T'_{do}	<u>OPEN CIRCUIT TIME CONSTANT</u> - The time constant of the field winding with the stator open circuited and with negligible external resistance and inductance in the field circuit. Field resistance at room temperature (20°C) is used in this calculation.
		$$T'_{do} = \frac{(L_F)}{(R_F)(N_{CO})} = \frac{(161)}{(154)(146a)}$$
(177)	T_a	<u>ARMATURE TIME CONSTANT</u>
(178)	T'_d	<u>TRANSIENT TIME CONSTANT</u>
(180)	F_{SC}	<u>SHORT-CIRCUIT AMPERE-TURNS</u>--The field ampere-turns required to circulate rated line amperes in a three-phase short circuit at the machine terminals.
		$$F_{SC} = \frac{(X_d)}{100}\ 2\left[F_g + F_{g2}\right]$$ $$= \frac{(133)}{100}\ 2\left[(96) + (123)\right]$$
(181)	SCR	<u>SHORT CIRCUIT RATIO</u>

(182)	I^2R_F	<u>FIELD I^2R</u> - at no load. The copper loss in the field winding is calculated with cold field resistance at 20°C for no load condition. Field $I^2R = (I_{FNL})^2 (R_{f\ cold})(N_{CO})$ $= (127a)^2 (154)(146a)$

(183)	F&W	FRICTION & WINDAGE LOSS - The best results are obtained by using existing data. For ratioing purposes, the loss can be assumed to vary approximately as the 5/2 power of the rotor diameter and as the 3/2 power of the RPM. When no existing data is available, the following calculation can be used for an approximate answer. Insert 0. when computer is to calculate F&W. Insert actual F&W when available. Use same value for all load conditions.

$$F\&W = 2.52 \times 10^{-6} (d_r)^{2.5} (\ell_p) (RPM)^{1.5}$$

$$= 2.52 \times 10^{-6} (11a)^{2.5} (76) (7)^{1.5}$$

For gases or fluids other than standard air, the fluid density and viscosity must be considered. The formula given in the manual can be modified by the factors

$$\left(\frac{\rho}{.0765}\right)^{.8} \left(\frac{\mu}{.0435}\right)^{.2}$$

where ρ = density - Lbs FT^{-3}

μ = viscosity LBS FT^{-1} HR^{-1}

.0765 = density std. air

.0435 = viscosity std. air

(184)	W_{TNL}	STATOR TEETH LOSS - at no load.
(185)	W_c	STATOR CORE LOSS
(186)	W_{NPL}	POLE FACE LOSS - at no load.
(187)	K_1	
(188)	K_2	
(189)	K_3	
(190)	K_4	
(191)	K_5	
(192)	K_6	
(194)	I^2R	STATOR I^2R - at no load.
(195)	--	EDDY LOSS - at no load.
(196)	--	TOTAL LOSSES - at no load. Sum of all losses Total losses = (Field I^2R) + (F&W) + (Stator Teeth Loss) + (Stator Core Loss) + (Pole Face Loss) = (182) + (183) + (184) + (185) + (186) The N. L. calculations should all be repeated now for 100% load.

(197a)	$\phi_{\ell\ell}$	LEAKAGE FLUX PER POLE at 100% load
		$\phi_{\ell\ell} = \phi_{\ell}\left\{\frac{(e_d)(F_g) + \left[1 + \cos(\theta)\right](F_T) + (F_C)}{(F_g) + (F_T) + (F_C)}\right\}$
		$= (100a)\left\{\frac{(198)(96) + \left[1 + \cos(198a)\right](97) + (98)}{(96) + (97) + (98)}\right.$
(198)	e_d	Where $e_d = \cos\epsilon + \frac{(X_d)}{100}\sin\Psi$
		$= \cos(198a) + \frac{(133)}{100}\sin(198a)$
(198a)	θ	Where $\theta = \cos^{-1}\left[(\text{Power Factor})\right]$
		$= \cos^{-1}\left[(9)\right]$
		Where $\Psi = \tan^{-1}\left[\frac{\sin(\theta) + (X_q)/(100)}{\cos(\theta)}\right]$
		$= \tan^{-1}\left[\frac{\sin(198a) + (134)/(100)}{\cos(198a)}\right]$
		Where $\epsilon = \Psi - \theta = (198a) - (198a)$
(198b)	ϕ_{8L}	LEAKAGE FLUX BETWEEN FLUX PLATES @ F.L. (Kilolines)
		$\phi_{8L} = (\phi_8)\ \frac{(\phi_{\ell\ell})}{(\phi_{\ell})} = (103b)\left[\frac{(196a)}{(100a)}\right]$

(207)	$\emptyset_{7L}$	<u>FLUX LEAKAGE FROM STATOR TO YOKE UNDER LOAD</u>
		(one side of stator only)
		$\emptyset_{7L} = (P_7) \left\{ (F_{PL}) + (e_d)(F_g) + (F_T) \left[1 + \cos(\theta)\right] + (F_c) \right\} \times 10^{-3}$
		$= (86) \left\{ (213c) + (198)(96) + (97) \left[1 + \cos(198a)\right] + (98) \right\} \times 10^{-3}$
(213)	$\emptyset_{PL}$	<u>FLUX PER POLE</u> at 100% load
		For P. F. .0 to .95
		$\emptyset_{PL} = (\emptyset_P) \left[(e_d) - \frac{.93(X_{ad})}{100} \sin(\Psi) \right]$
		$= (92) \left[(198) - \frac{.93(131)}{100} \sin(198a) \right]$
		For P. F. .95 to 1.0
		$\emptyset_{PL} = (\emptyset_P)(K_c) = (92)(9a)$
(213a)	$\emptyset_{PTL}$	<u>TOTAL FLUX PER POLE</u> at 100% load
		$\emptyset_{PTL} = \emptyset_{PL} + \frac{2(\emptyset_{\ell\ell})}{(P)} = (213) + \frac{2(197a)}{(6)}$
(213b)	B_{PL}	<u>FLUX DENSITY AT BASE OF POLE</u> at 100% load
		$B_{PL} = \frac{\emptyset_{PTL}}{ap} = \frac{(213a)}{(79)}$

(213c)	F_{PL}	AMPERE TURNS PER POLE at 100% load $F_{PL} = (\ell_p) \left[NI/in \text{ @ density } (B_{PL}) \right]$ $= (76) \left[\text{Look up ampere turns/inch on rotor magnetization curve given in (18) at density (213b)} \right]$
(221)	ϕ_{g2L}	FLUX CROSSING THE AUXILIARY AIR GAP under load $\phi_{g2L} = (\phi_{PTL})\frac{(P)}{2} + (\phi_{7L}) + (\phi_{8L})$ $= (213a)\frac{(6)}{2} + (207) + (198b)$
(224)	B_{g2L}	FLUX DENSITY IN AUXILIARY GAP (g_2) under load $B_{g2L} = \frac{(\phi_{g2L})}{(A_{g2})} = \frac{(221)}{(70)}$
(225)	F_{g2L}	AUXILIARY AIR GAP AMPERE TURN DROP under load $F_{g2L} = \frac{(B_{g2L})}{3.19}(g_2) \times 10^3 = \frac{(224)}{3.19}(59a) \times 10^3$
(226)	ϕ_{5L}	COIL LEAKAGE FLUX under load $\phi_{5L} = (P_5) \left[(F_{yL}) + (F_{PL}) + (F_{g2L}) + (e_d)(F_g) + F_T \left[1 + \cos(\theta) \right] + F_c \right] \times 10^{-3}$ $= (84) \left[(229c) + (213c) + (225) + (198)(96) + (97) \left[1 + \cos(198a) \right] + (98) \right] \times 10^{-3}$

(227)	ϕ_{y2L}	FLUX IN END-BELL SECTION OF THE YOKE under load $\phi_{y2L} = (\phi_{g2L}) + \phi_{5L}$ $= (221) + (226)$
(228)	B_{y2L}	DENSITY IN END-BELL SECTION OF YOKE AT THE SMALLEST AREA SECTION under load $B_{y2L} = \frac{\phi_{y2L}}{A_{y2}} = \frac{(227)}{(124)}$
(229)	F_{y2L}	AMPERE TURN DROP IN END-BELL SECTION OF YOKE under load. $F_{y2L} = \left[\frac{(D)-(d_{y2})}{6}\right] \left[\text{NI/inch @ density } (B_{y2L})\right]$ $= \left[\frac{(12)-(78)}{6}\right] \left[\begin{array}{l}\text{Look up on yoke magnetization curve} \\ \text{given in (18) at density (228)}\end{array}\right]$
(229b)	B_{yL}	FLUX DENSITY IN THE HOUSING SECTION OF THE YOKE under load. $B_{yL} = \frac{(\phi_{g2L})}{(A_y)} \quad \frac{(221)}{(124a)}$

(229c)	F_{yL}	<u>AMPERE TURN DROP THROUGH THE HOUSING SECTION OF THE YOKE</u> under load, using 1/2 total length of housing. $F_y = (\ell_y)\left[\text{NI/inch @ density } (B_{yL})\right]$ $= (78)\left[\text{Look up on yoke magnetization curve given in (18) @ density (229b)}\right]$
(236)	F_{FL}	<u>TOTAL AMPERE TURN DROP</u> at full load $= 2\left\{(F_{g2L})+(F_{yL})+(F_{y2L})+(F_{PL})+(e_d)(F_g)+(F_T)\left[1+\cos(\theta)\right]+\frac{F_c}{2}\right\} \times 10^{-3}$ $= 2\left[(225)+(229c)+(229)+(213c)+(198)(96)+(97)\left[1+\cos(1\;3a)\right]+\frac{(98)}{2}\right] \times 10^{-}$
(237)	I_{FFL}	<u>FIELD CURRENT</u> under load $I_{FFL} = (F_{FL})/(N_F)(N_{CO}) = (236)/(146)(146a)$
(239)	S_{FL}	<u>CURRENT DENSITY</u> at 100% load Current Density $= (I_{FFL})/(a_{cf}) = (237)/(153)$
(238)	E_{FFL}	<u>FIELD VOLTS</u> at 100% load - This calculation is made with hot field resistance at expected temperature at 100% load. Field Volts $= (I_{FFL})(R_{f\ hot})(N_{CO}) = (237)(155)(146a)$

(241) I^2R_{FL} **FIELD I^2R** at 100% load - The copper loss in the field winding is calculated with hot field resistance at expected temperature for 100% load condition.

$$\text{Field } I^2R = (I_{FL})^2 (R_{F\ hot})(N_{CO}) - (237)^2(155)(146a)$$

(242) W_{TFL} **STATOR TEETH LOSS** at 100% load - The stator tooth loss under load increases over that of no load because of the parasitic fluxes caused by the ripple due to the rotor damper bar slot openings.

$$W_{TFL} = \left\{2\left[.27\ \frac{(X_d)}{100}\ \frac{(\%\ \text{Load})}{100}\right]^{1.8} + 1\right\} W_{TNL}$$

$$= \left\{2\left[.27\ \frac{(133)}{100}\ 1\right]^{1.8} + 1\right\} (184)$$

(243) W_{PFL} **POLE FACE LOSS** at 100% load

$$W_{PFL} = \left\{\left[\frac{(K_{sc})(I_{PH})\frac{(\%\ \text{Load})}{100}\ (n_s)}{(C)(F_g)}\right]^2 + 1\right\}(W_{PNL})$$

$$= \left\{\left[\frac{(243)(8)\ 1\ (30)}{(32)(96)}\right]^2 + 1\right\}(186)$$

(K_{sc}) is obtained from Curve F-3

(245)	I^2R_L	STATOR I^2R at 100% load - The copper loss based on the D. C. resistance of the winding. Calculate at the maximum expected operating temperature. $I^2R = (m)(I_{PH})^2 (R_{SPH\ hot})$ $= (5)(8)^2 (54)$
(246)	--	EDDY LOSS - Stator I^2R loss due to skin effect Eddy Loss $= \left[\frac{(EF_{top}) + (EF_{bot})}{2} - 1\right]$ (Stator I^2R) $= \left[\frac{(55) + (56)}{2} - 1\right] (245)$
(247)	--	TOTAL LOSSES at 100% load - sum of all losses at 100% load Total Losses = (Field I^2R) + (F&W) + (Stator Teeth Loss) + (Stator Core Loss) + (Pole Face Loss) + (Stator I^2R) + (Eddy Loss) = (241) + (183) + (242) + (185) + (243) + (245) + (246)
(248)	--	RATING IN KILOWATTS at 100% load Rating $= 3(E_{PH})(I_{PH})$ (P. F.) $\times 10^{-3}$ $= 3(4)(8)(9) \times 10^{-3}$

(249)	--	$\underline{\text{RATING PLUS LOSSES}} = (248) + (247) \times 10^{-3}$
(250)	--	$\underline{\%\ \text{LOSSES}} = \dfrac{\text{Losses x (100)}}{\text{Rating Plus Losses}}$
		$= \dfrac{(247) \times 10^{-3} \times 10^{2}}{(249)}$
(251)	--	$\underline{\%\ \text{EFFICIENCY}} = 100\% - \%\ \text{Losses}$
		$= 100\% - (250)$
		These items can be recalculated for any load condition by simply inserting the values that correspond to the % load being calculated.
		Values for F&W (183) and W_C (Stator Core Loss) (185) do not change with load.

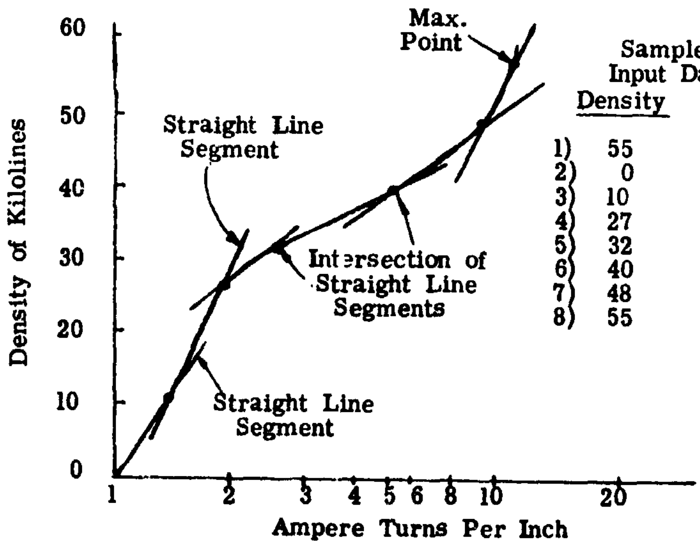
(1)	--	DESIGN NUMBER
(2)	KVA	GENERATOR KVA
(3)	E	LINE VOLTS
(4)	E_{PH}	PHASE VOLTS
(5)	m	PHASES
(5a)	f	FREQUENCY
(6)	P	POLES
(7)	RPM	SPEED
(8)	I_{PH}	PHASE CURRENT
(9)	P. F.	POWER FACTOR
(9a)	K_c	ADJUSTMENT FACTOR
(10)	--	LOAD POINTS
(11)	d	STATOR PUNCHING I.D.
(11a)	d_r	ROTOR O.D.
(12)	D	PUNCHING O.D.
(13)	ℓ	GROSS STATOR CORE LENGTH
(14)	n_v	RADIAL DUCTS
(15)	b_v	RADIAL DUCT WIDTH
(16)	K_i	STACKING FACTOR
(17)	ℓ_s	SOLID CORE LENGTH

(18) **MATERIAL** - This input is used in selecting the proper magnetization curves for stator, yoke & pole.

Separate spaces are provided on the input sheet for each section mentioned above. Where curves are available on card decks, used the proper identifying code. Where card decks are not available submit data in the following manner:

The magnetization curve must be available on semi-log paper. Typical curves are shown in this manual on Curves F15 & F16. Draw straight line segments through the curve starting with zero density. Record the coordinates of the points where the straight line segments intersect. Submit these coordinates as input data for the magnetization curve. The maximum density point must be submitted first.

Refer to Figure below for complete sample



Sample Input Data

	Density	NI
1)	55	Max.
2)	0	0
3)	10	1.5
4)	27	1.9
5)	32	2.5
6)	40	4.9
7)	48	9.0
8)	55	12.0

(19)	k	WATTS LB
(20)	B	DENSITY
(21)		TYPE OF STATOR SLOT
(22)		ALL SLOT DIMENSIONS
(23)	Q	STATOR SLOTS
(24)	h_c	DEPTH BELOW SLOTS
(25)	q	SLOTS PER POLE PER PHASE
(26)	τ_s	STATOR SLOT PITCH
(27)	$\tau_s 1/3$	STATOR SLOT PITCH
(28)	--	TYPE OF WINDING
(29)	--	TYPE OF COIL
(30)	n_s	CONDUCTORS PER SLOT
(31)	y	THROW
(31a)		PER UNIT OF POLE PITCH SPANNED
(32)	C	PARALLEL PATHS
(33)	--	STRAND DIA. OR WIDTH
(34)	N_{ST}	NUMBER OF STRANDS PER CONDUCTOR IN DEPTH
(34a)	N'_{ST}	NUMBER OF STRANDS PER CONDUCTOR
(35)	d_b	DIAMETER OF BENDER PIN
(36)	ℓ_{e2}	COIL EXTENSION BEYOND CORE
(37)	h_{ST}	HEIGHT OF UNINSULATED STRAND
(38)	h'_{ST}	DISTANCE BETWEEN CENTERLINES OF STRANDS IN DEPTH

(39)	--	STATOR COIL STRAND THICKNESS
(40)	τ_{SK}	SKEW
(41)	τ_P	POLE PITCH
(42)	K_{SK}	SKEW FACTOR
(42a)		PHASE BELT ANGLE
(43)	K_d	DISTRIBUTION FACTOR
(44)	K_p	PITCH FACTOR
(45)	n_e	TOTAL EFFECTIVE CONDUCTORS
(46)	a_c	CONDUCTOR AREA OF STATOR WINDING
(47)	S_S	CURRENT DENSITY
(48)	L_E	END EXTENSION LENGTH
(49)	ℓ_t	1/2 MEAN TURN
(50)	X_s °C	STATOR TEMP °C
(51)	ρ_s	RESISTIVITY OF STATOR WINDING
(52)	ρ_S (hot)	RESISTIVITY OF STATOR WINDING
(53)	R_{SPH} (cold)	STATOR RESISTANCE/PHASE
(54)	R_{SPH} (hot)	STATOR RESISTANCE/PHASE
(55)	EF (top)	EDDY FACTOR TOP
(56)	EF (bot)	EDDY FACTOR BOTTOM

(57)	b_{tm}	STATOR TOOTH WIDTH
(57a)	$b_{t\ 1/3}$	STATOR TOOTH WIDTH
(58)	b_t	TOOTH WIDTH AT STATOR I.D. in inches
(59)	g	MAIN AIR GAP in inches
(59a)	g_2	AUXILIARY AIR GAP in inches
(60)	C_X	REDUCTION FACTOR
(61)	K_X	FACTOR TO ACCOUNT FOR DIFFERENCE in phase current in coil sides in same slot
(62)	λ_i	CONDUCTOR PERMEANCE
(63)	K_E	LEAKAGE REACTIVE FACTOR
(64)	λ_E	END WINDING PERMEANCE
(64a)	λ_z	SPECIAL LEAKAGE PERMEANCE - For machines having a section of the pole that is approximately a full pole-pitch wide, an additional leakage permeance must be added to the slot and end-turn leakage permeances. This permeance is that of the leakage path from one pole into a tooth top and from tooth

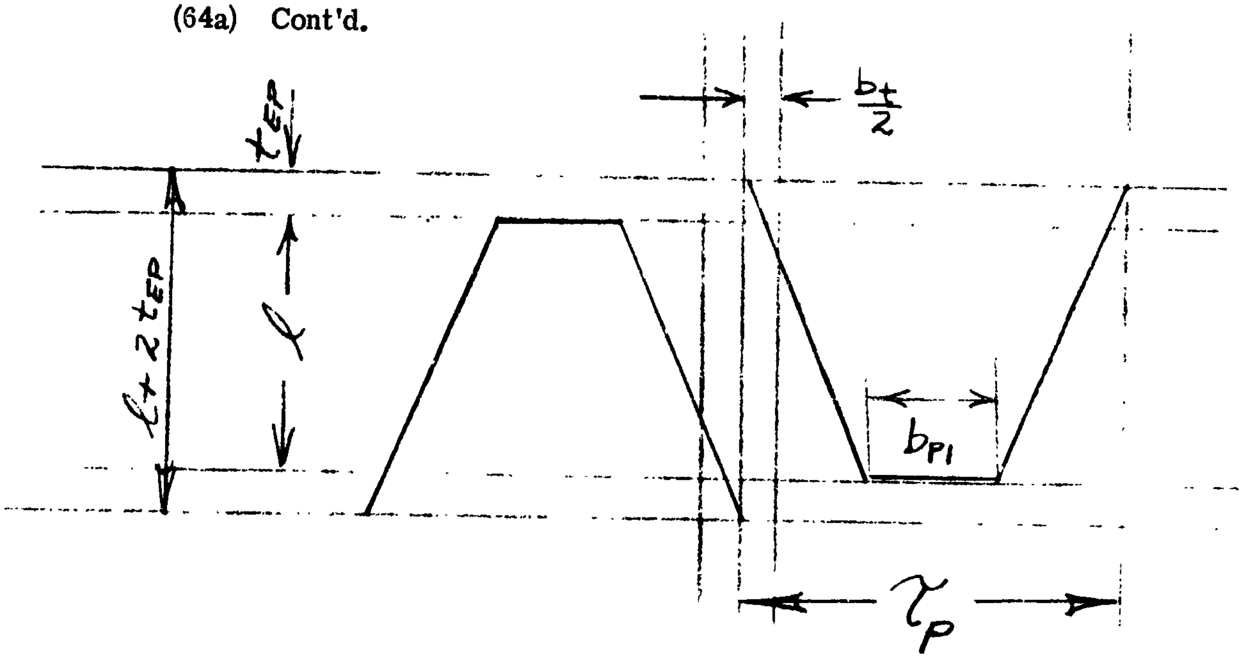
(64a) Cont'd.

top back into the adjacent pole. The leakage is similar to Zig Zag leakage and by increasing the stator leakage reactance, can reduce the output of the generator significantly.

This same leakage can be used to purposely limit the output of the generator and make it current limited. The presence of this additional leakage can be good or bad depending upon what is wanted from the generator. The important thing is for the designer to be aware that it is there.

In many cases, the designer should estimate the specific permeance λ_z since the pole base will be more or less than a full pole pitch wide and the following formula will not suffice.

(64a) Cont'd.



$$\lambda_z = (C_X)\,\frac{20}{(m)(q)}\left\{\frac{\text{area of pole over tooth when tooth is on centerline between poles}}{2\,\ell\, g}\right\}$$

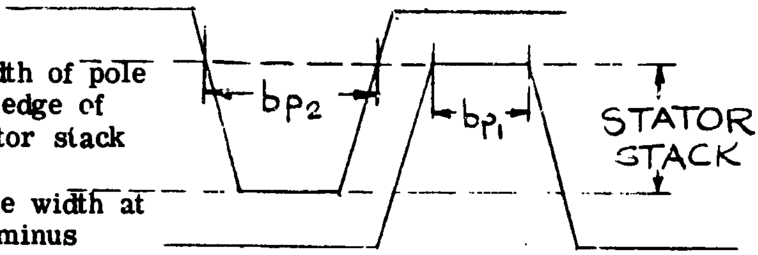
$$\lambda_z = (C_X)\,\frac{20}{(m)(q)}\left\{\frac{b_t\,(\tau_p - b_{p1})\,(\ell + 2\,t_{EP})\,\frac{(\tau_p - b_{p1})}{\tau_p}}{2\,\ell\,g}\right\}$$

(65)	--	WEIGHT OF COPPER
(66)	--	WEIGHT OF STATOR IRON
(67)	K_s	CARTER COEFFICIENT
(68)	--	MAIN AIR GAP AREA
(69)	g_e	EFFECTIVE AIR GAP

(70)	A_{g2}	AREA OF AUXILIARY AIR GAP $A_{g2} = \pi(d_{g2})(\ell_{g2}) = \pi(78)(78)$
(71)	C_1	THE RATIO OF MAXIMUM FUNDAMENTAL of the field form to the actual maximum of the field form
(72)	C_W	WINDING CONSTANT-
(73)	C_P	POLE CONSTANT
(74)	C_M	DEMAGNETIZING FACTOR
(75)	C_q	CROSS MAGNETIZING FACTOR
(76)	--	POLE DIMENSION LOCATIONS

b_{p2} = width of pole at edge of stator stack

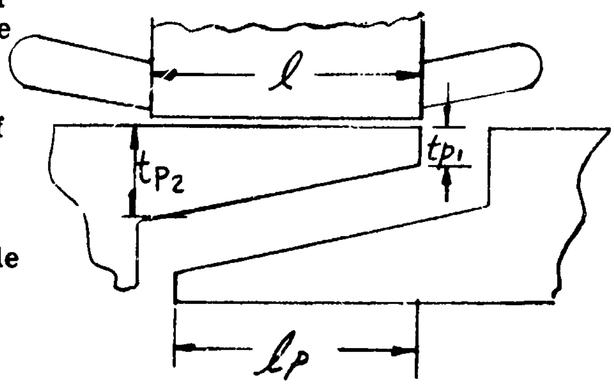
b_{p1} = pole width at terminus



t_{p2} = thickness of pole at edge of stator

t_{p1} = thickness of pole at terminus

ℓ_p = length of pole



(77)	α	<u>POLE EMBRACE</u> $$\alpha = \frac{b_{p1} + b_{p2}}{2(\tau_p)} = \frac{(76) + (76)}{2(41)}$$
(77a)	--	Items immediately following deal with the calculation of rotor and stator leakage permeances. Illustrations are included to help identify the permeance areas and to locate the flux leakage paths. The computer program will handle the calculation of permeances P_1, P_2, P_3 and P_4 either of two ways: 1. P_1 through P_4 can be calculated by the computer. For this case, insert 0.0 on the input sheet for P_1 through P_4. 2. P_1 through P_4 can be calculated by the designer. For this case, insert the actual calculated value on the input sheet for P_1 through P_4. Permeance P_5 and P_7 must be calculated by the designer and the calculated value must be inserted on the input sheet. The computer will not calculate these two permeance values because of the various possible field coil locations.

Permeance calculations P_1 through P_7 are all based on the equation $P = \frac{\mu (\text{area})}{\ell}$

Where μ = 3.19

Area = cross-sectional area perpendicular to the leakage flux.

ℓ = length of flux leakage path

Many of the equations used in this section are taken from Roter's "Electromagnetic Devices". Refer to the Appendix for the Roter's formulae.

(78) -- **ROTOR AND STATOR DIMENSIONS**

ℓ_{g2} = axial length of gap (g_2)

d_{y2} = diameter of yoke (end bell section) at narrowest section

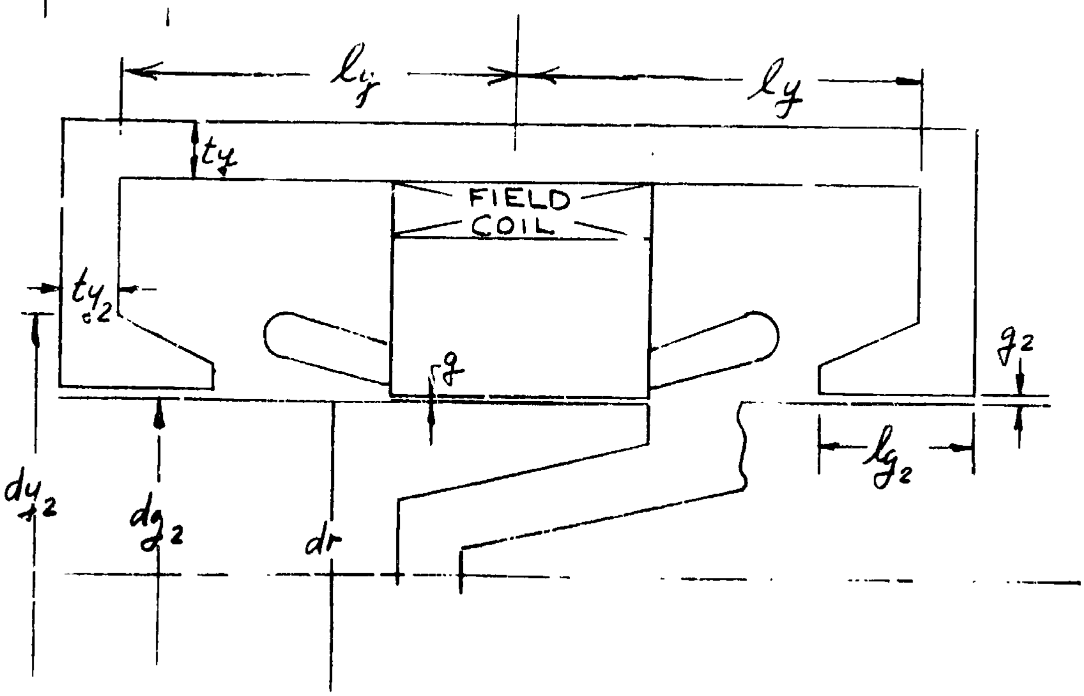
d_{g2} = rotor diameter at auxiliary air gap

ℓ_y = effective length of yoke ÷ 2

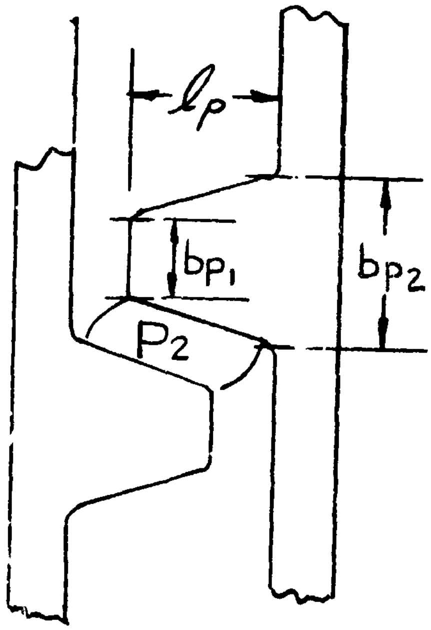
t_{y2} = thickness of end bell section of yoke

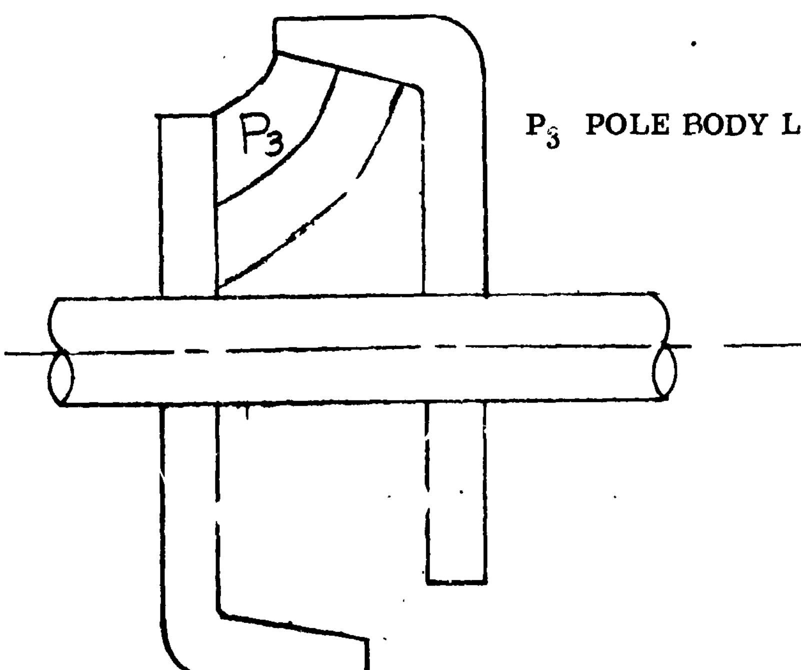
t_y = thickness of housing section of yoke

d_r = rotor diameter at main air gap



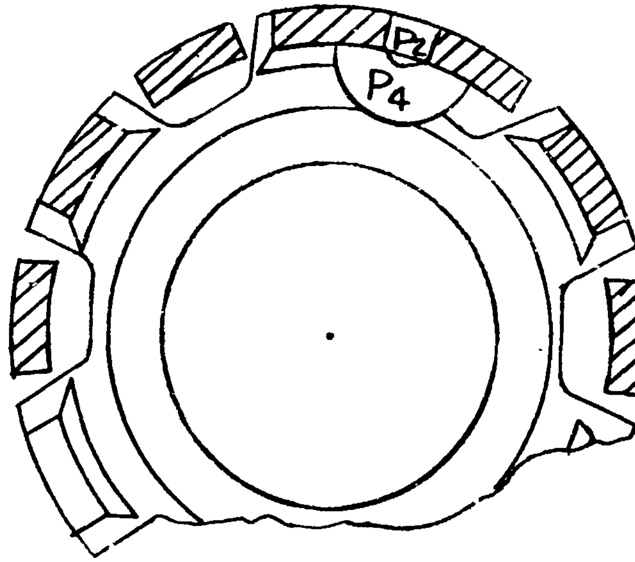
P_2 POLE HEAD SIDE LEAKAGE



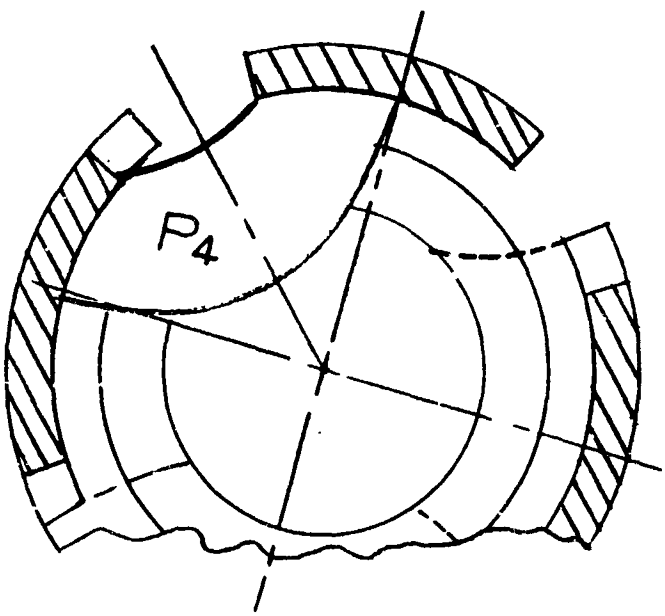


P_3 POLE BODY LEAKAGE

Figure M-12



P_4 IN A 12 POLE GENERATOR

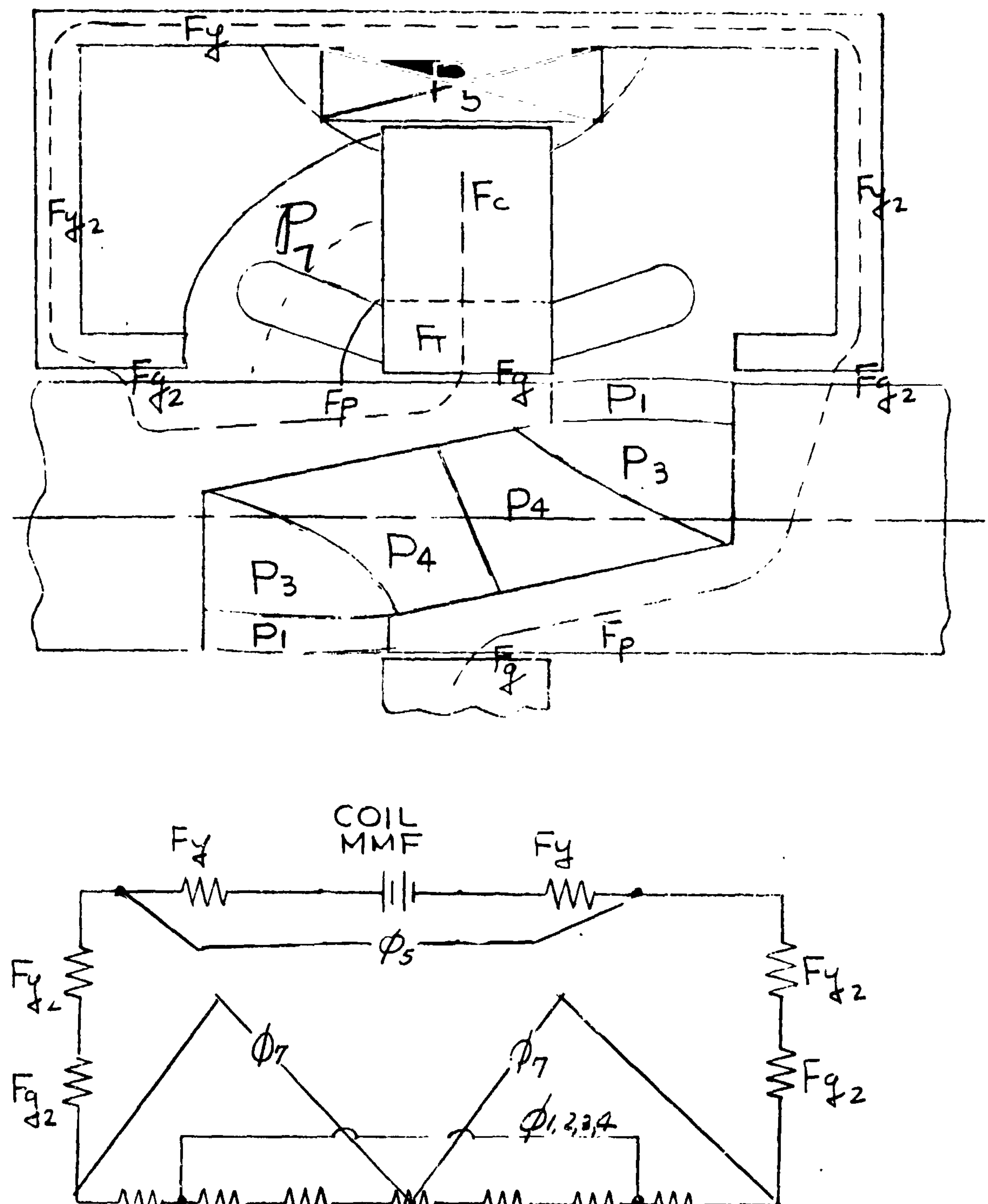


P_4 IN A 4 POLE GENERATOR

Figure M-13

(79)	a_p	POLE AREA - The effective cross sectional area of the pole $a_p = (b_{p2})(t_{p2}) = (76)(76)$
(80)	P_1	POLE HEAD END LEAKAGE - This can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure M-4. $P_1 = \frac{3.19\,(b_{p1})(t_{p1})}{\ell_1} = \frac{3.19\,(76)(76)}{(80a)}$
(80a)	ℓ_1	ℓ_1 = length of permeance path P_1 and must be obtained from design layout. Must be given on input sheet when $P_1 = 0$.
(81)	P_2	POLE HEAD SIDE LEAKAGE - This input can be either 0.0 or the actual value if available. Refer to Item (86) for explanation. See Figure M-12. $P_2 = \frac{3.19\left\{(\ell_p)\left[\frac{(t_{p2}) + (t_{p1})}{2}\right]\right\}}{(\ell_2)} = \frac{3.19\left\{(76)\left[\frac{(76) + (76)}{2}\right]\right\}}{(81a)}$
(81a)	ℓ_2	LENGTH OF PERMEANCE PATH P_2 in inches $\ell_2 = \tau_p - \left[\frac{(b_{p1}) + (b_{p2})}{2}\right] = (41) - \left[\frac{(76) + (76)}{2}\right]$

(82)	P_3	<u>POLE BODY END LEAKAGE</u> - This input can be either 0.0 or the actual value if available. Refer to Item (86) for explanation. See Figure M-12 location. $$P_3 = \frac{6.28}{\pi}\left[3\,\frac{(b_{p1}) + (b_{p2})}{4}\right]\ln\frac{(r_3)}{(r_4)}$$ $$= \frac{6.28}{\pi}\left[3\,\frac{(76) + (76)}{4}\right]\ln\frac{(82b)}{(82c)}$$
(82b)	r_3	$r_3 = \ell_1 = (80a) =$ length of permeance path P_1
(82c)	r_4	$r_4 = (\ell_1) + \frac{(\ell)}{2} = (80a) + \frac{(13)}{2}$
(83)	P_4	<u>POLE BODY SIDE LEAKAGE</u> - This input can be either 0.0 or the actual value if available. Refer to Item (77a) for explanation. See Figure M-13 for location. When (6) > 4 $$P_4 = \frac{3.19\,(\ell_p)}{\pi}\,\ell n\left[1 + \frac{(b_{p1}) + (b_{p2})}{2(Z)}\right]$$ $$= \frac{3.19(76)}{\pi}\,\ell n\left[1 + \frac{(76) + (76)}{2\,(83)}\right]$$ Where $Z = T_p - \left[\frac{(b_{p1}) + (b_{p2})}{2}\right] = 41 - \left[\frac{(76) + (76)}{2}\right]$



Fy
Fc
Fy2
P7
FT
Fy2
Fp
Fg
P1
Fg2
P3
P4
P4
P3
P1
Fp
Fg
COIL
MMF
Fy
Fy
φ5
Fy2
Fy2
φ7
φ7
Fg2
Fg2
φ1,2,3,4
Fp
Fg
FT
Fc
FT
Fg
Fp

Figure M-14

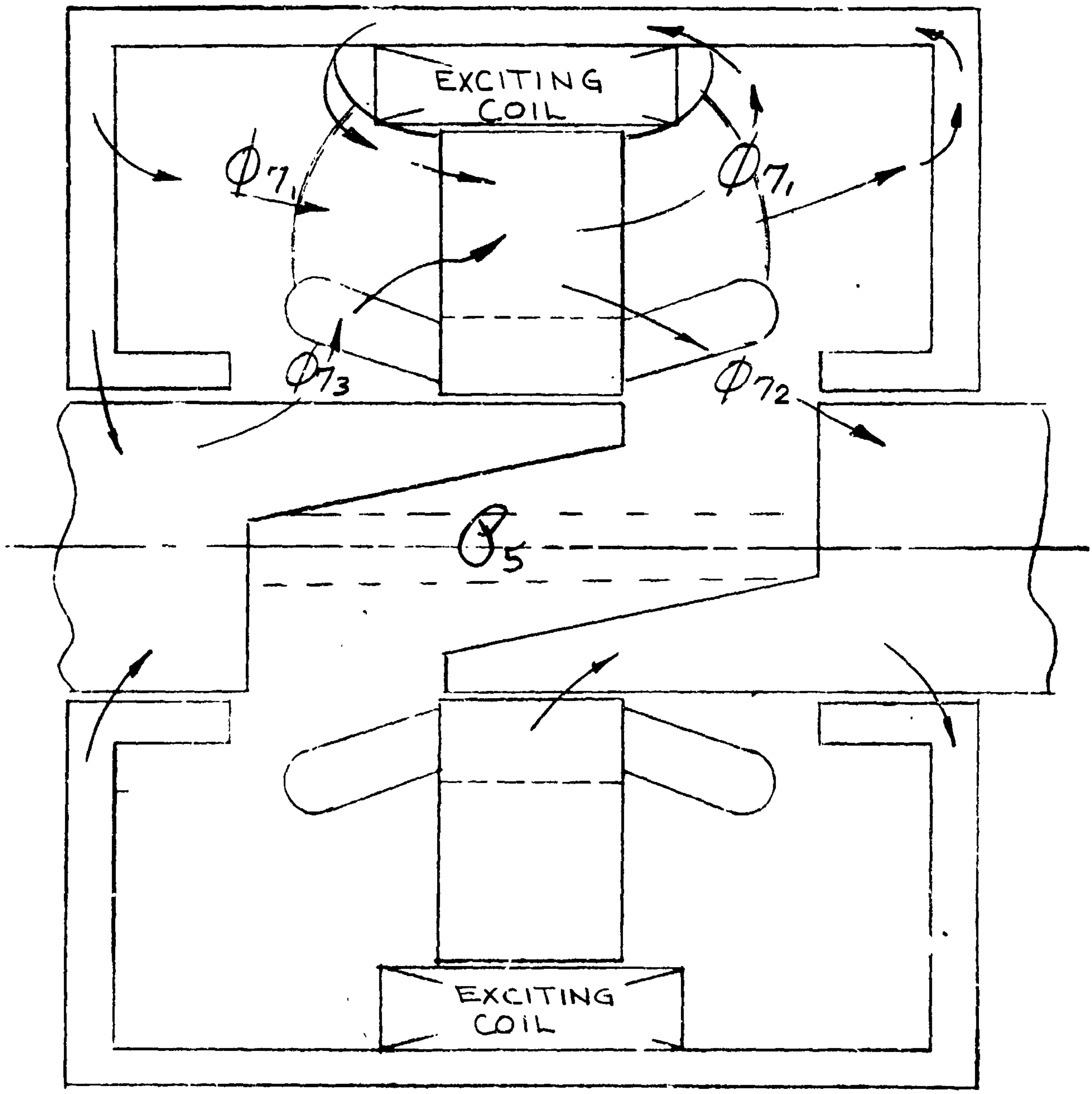
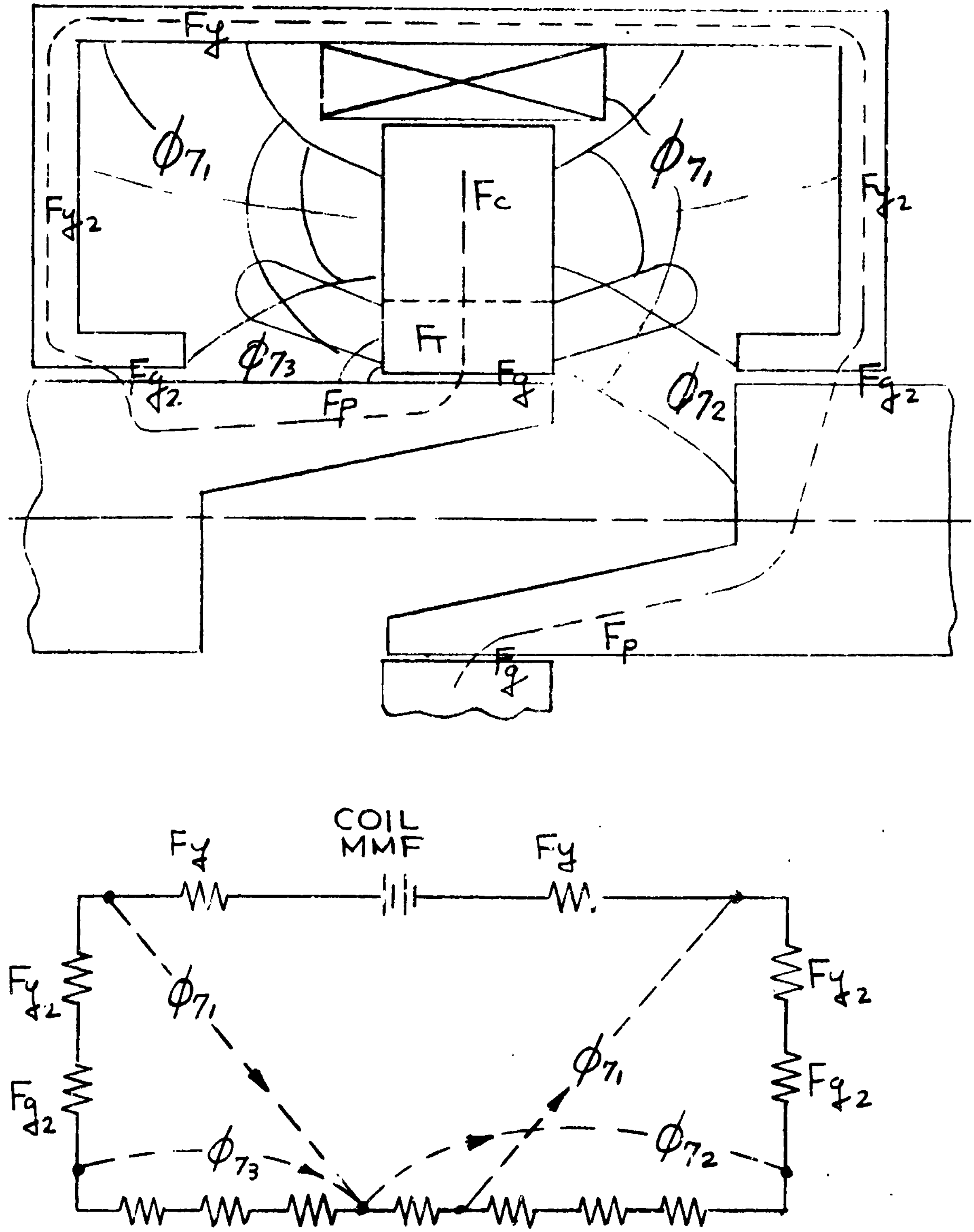


Figure M-15



Fy
Fy2
Fy2
Fc
FT
Fg
Fy2
Fp
Fg
Fg2
Fp
Fg
COIL
MMF
Fy
Fy
Fy2
Fy2
Fg2
Fg2
Fp
Fg
FT
Fc
FT
Fg
Fp

Figure M-16

When (6) $\leq$ 4

$$P_4 = \frac{3.19\ (\ell_p)}{\pi}\ \frac{3}{2}\ \ell n \left[1 + \frac{(b_{p1}) + (b_{p2})}{2(Z)}\right]$$

$$= \frac{3.19\ (76)}{\pi}\ \frac{3}{2}\ \ell n \left[1 + \frac{(76) + (76)}{2\ (83)}\right]$$

(84)	P_5	COIL LEAKAGE PERMEANCE - This permeance must be calculated by the designer and the calculated value must be inserted on the input sheet. Refer to Figure M-14 which shows the location of the coil.
(86)	P_7	STATOR TO FRAME AND ROTOR LEAKAGE PERMEANCE - Refer to Figure M-14 for location. This permeance is actually broken down into three parts: P_{71} leakage to yoke; P_{72} leakage to shaft; P_{73} leakage to rotor pole. In this design manual, the three permeances are added and treated as a single leakage. The same condition applies to P_7 and P_5. The designer must calculate P_7 and insert the calculated value on the input sheet.

(86a)	P_8	FLUX PLATE TO FLUX PLATE LEAKAGE PERMEANCE This permeance must be calculated by the designer and the value must be inserted on the input sheet. Location per Figure M-5
(87)	--	The next set of calculations deals with the no load saturation. When the no load saturation data is required at various voltages, insert 1. on the input sheet for "no load sat". The computer will then calculate the complete no load saturation curve at 80, 90, 100, 110, 120, 130, 140, 150 and 160% of rated volts. When the complete saturation data is not necessary, insert 0. on the input sheet and the computer will calculate the 100% volts data.
(88)	$\emptyset_T$	TOTAL FLUX IN KILOLINES
(91)	B_t	TOOTH DENSITY
(92)	$\emptyset_P$	FLUX PER POLE
(94)	B_c	CORE DENSITY

(95)	B_g	GAP DENSITY
(96)	F_g	AIR GAP AMPERE TURNS
(97)	F_T	STATOR TOOTH AMPERE TURNS
(98)	F_c	STATOR CORE AMPERE TURNS
(98a)	F_s	STATOR AMPERE TURNS
(99)	$\emptyset_7$	STATOR TO YOKE LEAKAGE FLUX - The leakage flux from the stator to the yoke. $\emptyset_7 = \left[(F_c) + (F_T) + (F_g) + (F_p)\right] (P_7) \times 10^{-3}$ $= \left[(98) + (97) + (96) + (104a)\right] (86) \times 10^{-3}$ The items that follow will be calculated for variable loads. The first set of calculations are at no load. The calculations will then be repeated for 100% load. For other values of load, the same calculations are repeated with the proper percent load inserted.

(100a)	ϕ_ℓ	<u>ROTOR LEAKAGE FLUX</u> - at no load $\phi_\ell = (P)\left[2(F_g) + 2(F_T) + (F_c)\right] \times \left[(P_1) + (P_2) + (P_3) + (P_4)\right] \times 10^{-3}$ $= (6)\left[2(96) + 2(97) + (98)\right] \times \left[(80) + (81) + (82) + (83)\right] \times 10^{-3}$
(102a)	ϕ_{PT}	<u>TOTAL FLUX PER POLE</u> - at no load $\phi_{PT} = (\phi_P) + \frac{2(\phi_\ell)}{(P)} = (92) + \frac{2(100a)}{(6)}$
(103a)	B_P	<u>POLE DENSITY</u> - The apparent flux density at the base of the pole. Note that no provision is made in this manual for calculating the density in the flux plate. It is, therefore, important to remember not to restrict the flux area through this section. $B_P = \frac{(\phi_{PT})}{(a_P)} = \frac{(102a)}{(79)}$
(103b)	ϕ_8	<u>FLUX PLATE TO FLUX PLATE</u> $\phi_8 = P_8\left[2(F_g) + 2(F_T) + F_c\right] \times 10^{-3}$ $= (86a)\left[2(96) + 2(97) + (98)\right] \times 10^{-3}$

(104a)	F_P	POLE AMPERE TURNS - at no load. The ampere turns per pole required to force the flux through the pole and spider at no load rated voltage. The no load pole ampere turns per pole are calculated as the product of (ℓ_P) times the NI per inch at the density (B_P). Use magnetization curve submitted per item (18) for rotor. $F_P = (\ell_P) \left[\text{NI/in @ density } (B_P) \right]$ $= (76) \left[\text{Look up on rotor magnetization curve given in (18) @ density (103a)} \right]$
(108)	ϕ_{g2}	AUXILIARY GAP (g_2) flux in kilolines. $\phi_{g2} = \phi_{PT} \frac{(P)}{2} + \phi_7 + \phi_8 = (102) \frac{(6)}{2} + (99) + (103b)$
(118)	ϕ_5	COIL LEAKAGE FLUX $\phi_5 = 2(P_5) \left[(F_{g2}) + (F_{y2}) + (F_P) + (F_g) + (F_T) + (F_C) \right] \times 10^{-3}$ $\phi_5 = 2(84) \left[(123) + (126) + (104a) + (96) + (97) + (98) \right] \times 10^{-3}$
(122)	B_{g2}	AUXILIARY GAP (g_2) FLUX DENSITY $B_{g2} = \frac{(\phi_{g2})}{(A_{g2})} = \frac{(108)}{(70)}$

(123)	F_{g2}	**AUXILIARY AIR GAP AMPERE TURNS**
		$F_{g2} = \frac{(B_{g2})}{3.19} (g_2) \times 10^3 = \frac{(122)}{3.19} (59a) \times 10^3$
(124)	A_{y2}	**AREA OF END BELL SECTION OF YOKE AT SMALLEST SECTION**
		$A_{y2} = \pi (d_{y2})(t_{y2}) = \pi (78)(78)$
(124a)	A_y	**AREA OF HOUSING PORTION OF YOKE**
		$A_y = \pi \left[(D) + (t_y)\right] (t_y)$
		$= \pi \left[(12) + (78)\right] (78)$
(125)	B_{y2}	**FLUX DENSITY IN END BELL SECTION OF YOKE @ N. L.**
		NOTE: The flux in the yoke is equal to the flux crossing the auxiliary gap (g).
		$B_{y2} = \frac{(\phi_{g2})}{(A_{y2})} = \frac{(108)}{(124)}$
(126)	F_{y2}	**AMPERE TURN DROP IN END BELL SECTION OF YOKE @ N. L.**
		$F_{y2} = \left[\frac{(D)-(d_{y2})}{6}\right] \left[\text{NI/inch @ } (B_{y2})\right]$
		$= \left[\frac{(12)-(78)}{6}\right] \left[\text{Look up on yoke magnetization curve @ density (125)}\right]$

(126a)	B_y	DENSITY IN HOUSING SECTION OF YOKE @ N. L.
		$B_y = \frac{(\phi_{g2}) + (\phi_5)}{A_y} = \frac{(108)+(118)}{(124a)}$
(126b)	F_y	AMPERE TURN DROP IN HOUSING SECTION OF YOKE
		using 1/2 total length of housing
		$F_y = (\ell_y)\left[\text{NI/inch at density } (B_y)\right]$
		$= (78)$ [Look up on yoke magnetization curve @ density (126a)]
(127)	F_{NL}	TOTAL AMPERE TURN DROP AROUND CIRCUIT @ N. L.
		$F_{NL} = 2\left[(F_y)+(F_{y2})+(F_{g2})+(F_P)+(F_g)+(F_T)+\frac{(F_c)}{2}\right]$
		$= 2\left[(126b)+(126)+(123)+(104)+(96)+(97)+\frac{(98)}{2}\right]$
(127a)	I_{FNL}	FIELD CURRENT - at no load
		$I_{FNL} = (F_{NL})/(N_F) = (127)/(146)$
(127b)	E_F	FIELD VOLTS - at no load. This calculation is made with cold field resistance at 20°C for no load condition.
		$E_F = (I_{FNL})(R_{f\ cold}) = (127a)(154)$
(127c)	S_F	CURRENT DENSITY

(128)	A	AMPERE CONDUCTORS per inch
(129)	X	REACTANCE FACTOR
(130)	X_ℓ	LEAKAGE REACTANCE in per cent $X_\ell = X\left[\lambda_i + \lambda_e + \lambda_z\right]$ $= (129)\left[(62) + (64) + (64a)\right]$ λ_z is explained under item (64a) and should be zero in most designs.
(131)	X_{ad}	REACTANCE - direct axis - This is the fictitious reactance due to armature reaction in the direct axis. (in per cent) $X_{ad} = \dfrac{.9\,(N_e)(I_{PH})(C_m)(K_d) \times 100}{2P\left[(F_g) + (F_{g2})\right]} = \dfrac{.9(45)(8)(74)(43) \times 100}{2(6)\left[(96) + (123)\right]}$
(132)	X_{aq}	REACTANCE - quadrature axis - This is the fictitious reactance due to armature reaction in the quadrature axis (in per cent). $X_{aq} = \dfrac{(C_q)(X_{ad})}{(C_m)(C_l)} = \dfrac{(75)(131)}{(74)(71)}$
(133)	X_d	SYNCHRONOUS REACTANCE - %
(134)	X_q	SYNCHRONOUS REACTANCE - quadrature axis - %

(145)	V_r	PERIPHERAL SPEED
(146)	N_F	NUMBER OF FIELD TURNS
(146a)	N_{co}	NUMBER OF FIELD COILS - One basic computer program is used for the single-coil and two-coil Lundell generators. This item is used in the computer program as a code for distinguishing one from the other.

(147)	ℓ_{tF}	MEAN LENGTH OF FIELD TURN INCHES.
(148)	--	FIELD CONDUCTOR DIA OR WIDTH in inches
(149)	--	FIELD CONDUCTOR THICKNESS in inches - Set this item = 0. for round conductor
(150)	$X_f{}^oC$	FIELD TEMP IN ^oC
(151)	ρ_f	RESISTIVITY of field conductor
(152)	ρ_f (hot)	RESISTIVITY of field conductor
(153)	a_{cf}	CONDUCTOR AREA OF FIELD WDG
(154)	R_f (cold)	COLD FIELD RESISTANCE @ 20^oC $R_f\ (cold) = (\rho_f)\ \frac{(N_F)(\ell_{tf})}{(a_{cf})} \times 10^{-6} = (151)\ \frac{(146)(147)}{(153)} \times 10^{-6}$
(155)	R_f (hot)	HOT FIELD RESISTANCE - Calculated at $X_f{}^oC$(103) $R_f\ (hot) = (\rho_{f\ hot})\ \frac{(N_F)(\ell_{tf})}{(a_{cf})} \times 10^{-6} = (152)\ \frac{(146)(147)}{(153)} \times 10^{-6}$
(156)	--	WEIGHT OF FIELD COIL in lbs. #'s of copper = $.321\ (N_F)(\ell_{tf})(a_{cf})$ $= .321(146)(6)(147)(153)$ Also refer to note in item (65)

(157)	--	WEIGHT OF ROTOR IRON - Because of the large number of different pole shapes, one standard formula cannot be used for calculating rotor iron weight. Therefore, the computer will not calculate rotor iron weight. The space is allowed on the input sheet for record purposes only. By inserting 0. in the space allowed for rotor iron weight, the computer will show "0." on the output sheet. If the rotor iron weight is available and inserted on input sheet, then the output sheet will show this same weight on the output sheet.
(160)	X_F	THE EFFECTIVE FIELD LEAKAGE REACTANCE - The reactance which added to the stator leakage reactance gives the transient reactance X'_{du}. When unit fundamental armature ampere turns are suddenly applied on the direct axis, an initial field current (I_f) will be induced. The value of this initial field current will be just enough to make the net flux interlinking the field because of the field current and the armature current zero. The field ampere turns will equal the armature ampere turns.

$$X_F = X_{ad}\left[1 - \frac{\frac{C_1}{C_m}}{2C_p + \frac{4}{\pi}\frac{\lambda_F}{\lambda_a}}\right]$$

$$X_F = (131)\left[1 - \frac{\frac{(71)}{(74)}}{2(73) + \frac{4}{\pi}\frac{(160)}{(160)}}\right]$$

$$\lambda_a = \frac{6.38d}{P g_e'} = \frac{6.38(11)}{(6)(160)}$$

$$g'_e = g_e\left[\frac{F_g - F_{g2}}{F_g}\right] = (69)\left[\frac{(96) - (123)}{(96)}\right]$$

$$\lambda_F = \frac{P_e}{\ell} = \frac{(160a)}{(13)}$$

(160a) | P_e | FIELD LEAKAGE PERMEANCE (flux lines/ampere turn

$$P_e = p\left[P_1 + P_2 + P_3 + P_4\right] + P_5$$
$$= (6)\left[(80) + (81) + (82) + (83)\right] + (84)$$

(161) | L_f | FIELD SELF-INDUCTANCE (henry)

$$L_f = N_F^2\,(P_e)\times 10^{-8}$$

$$= (146)^2\,(160a)\times 10^{-8}$$

(166)	X'_{du}	UNSATURATED TRANSIENT REACTANCE
(167)	X'_{d}	SATURATED TRANSIENT REACTANCE
(168)	X''_{d}	SUBTRANSIENT REACTANCE in direct axis
(169)	X''_{q}	SUBTRANSIENT REACTANCE in quadrature axis
(170)	X_2	NEGATIVE SEQUENCE REACTANCE
(172)	X_0	ZERO SEQUENCE REACTANCE
(173)	K_{xo}	
(174)	K_{x1}	
(175)	λ_{Bo}	
(176)	T'_{do}	OPEN CIRCUIT TIME CONSTANT - The time constant of the field winding with the stator open circuited and with negligible external resistance and inductance in the field circuit. Field resistance at room temperature (20°C) is used in this calculation. $T'_{do} = \frac{L_F}{R_F} = \frac{(161)}{(154)}$
(177)	r_a	ARMATURE TIME CONSTANT
(178)	T'_{d}	TRANSIENT TIME CONSTANT

(180)	F_{SC}	SHORT CIRCUIT AMPERE TURNS

SHORT-CIRCUIT AMPERE-TURNS--The field ampere-turns required to circulate rated line amperes in a three-phase short circuit at the machine terminals.

$$F_{SC} = \left(\frac{X_d}{100}\right)^2 \left[F_g + F_{g2}\right]$$

$$= \frac{(133)}{100}\ 2\left[(96) + (123)\right]$$

(181)	SCR	SHORT CIRCUIT RATIO
(182)	I^2R_F	FIELD I^2R - at no load. The copper loss in the field winding is calculated with cold field resistance at 20°C for no load condition. Field $I^2R = (I_{FNL})^2(R_{f\ cold}) = (127a)^2\ (154)$
(183)	F&W	FRICTION & WINDAGE LOSS - The best results are obtained by using existing data. For ratioing purposes, the loss can be assumed to vary approximately as the 5/2 power of the rotor diameter and as the 3/2 power of the RPM. When no existing data is available, the following calculation can be used for an approximate answer. Insert 0. when computer is to calculate F&W. Insert actual F&W when available. Use same value for all load conditions. $F\&W = 2.52 \times 10^{-6}\ (d_r)^{2.5}\ (RPM)^{1.5}\ (\ell_p)$ $= 2.52 \times 10^{-6}\ (11a)^{2.5}\ (7)^{1.5}\ (76)$

For gases or fluids other than standard air, the fluid density and viscosity must be considered. The formula given in the manual can be modified by the factors

$$\left(\frac{\rho}{.0765}\right)^{.8} \left(\frac{u}{.0435}\right)^{.2}$$

where ρ = density - Lbs FT^{-3}

μ = viscosity LBS FT^{-1} HR^{-1}

.0765 = density std. air

.0435 = viscosity Std air

(184)	W_{TNL}	STATOR TEETH LOSS
(185)	W_c	STATOR CORE LOSS
(186)	W_{NPL}	POLE FACE LOSS - at no load.
(187)	K_1	
(188)	K_2	
(189)	K_3	
(190)	K_4	
(191)	K_5	

(192)	K_6	
(194)	I^2R	STATOR I^2R - at no load.
(195)	--	EDDY LOSS - at no load.
(196)	--	TOTAL LOSSES - at no load.
		The N. L. calculations should all be repeated now for 100% load.
(196a)	$\phi_{\ell\ell}$	LEAKAGE FLUX PER POLE at 100% load
		$\phi_{\ell\ell} = \phi_{\ell}\left\{\frac{(e_d)(F_g) + \left[1 + \cos(\theta)\right](F_T) + (F_C)}{(F_g) + (F_T) + (F_C)}\right\}$
		$= (100)\left\{\frac{(198)(96) + \left[1 + \cos(198a)\right](97) + (98)}{(96) + (97) + (98)}\right.$
(198)	e_d	Where $e_d = \cos\epsilon + \frac{(X_d)}{100}\sin\Psi$
		$= \cos(198a) + \frac{(133)}{100}\sin(198b)$
(198a)	θ	Where $\theta = \cos^{-1}\left[(\text{Power Factor})\right]$
		$= \cos^{-1}\left[(9)\right]$
		Where $\Psi = \tan^{-1}\left[\frac{\sin(\theta) + (X_q)/(100)}{\cos(\theta)}\right]$
		$= \tan^{-1}\left[\frac{\sin(198a) + (134)/(100)}{\cos(198a)}\right]$

Where $\epsilon = \Psi - \theta = (198a) - (198a)$

(198b)	$\emptyset_{8L}$	LEAKAGE FLUX BETWEEN FLUX PLATES AT F.L. (Kilolines)
		$$\emptyset_{8L} = \frac{(\emptyset_{\ell\ell})}{(\emptyset_{\ell})} (\emptyset_8) = (103b)\ \frac{(196a)}{(100a)}$$
(207)	$\emptyset_{7L}$	FLUX LEAKAGE FROM STATOR TO YOKE UNDER LOAD (one side of stator only)
		$$\emptyset_{7L} = (P7)\left[(F_{PL}) + (e_d)(F_g) + (F_T)\left[1 + \cos(\theta)\right] + (F_c)\right] \times 10^{-3}$$ $$= (86)\left[(213c) + (198)(96) + (97)\left[1 + \cos(198a)\right] + (98)\right] \times 10^{-3}$$
(213)	$\emptyset_{PL}$	FLUX PER POLE at 100% load
		For P.F. .0 to .95
		$$\emptyset_{PL} = (\emptyset_P)\left[(e_d) - \frac{.93(X_{ad})}{100} \sin(\Psi)\right]$$ $$= (92)\left[(198) - \frac{.93(131)}{100} \sin(198a)\right]$$
		For P.F. .95 to 1.0
		$$\emptyset_{PL} = (\emptyset_P)(K_c) = (92)(9a)$$
(213a)	$\emptyset_{PTL}$	TOTAL FLUX PER POLE at 100% load
		$$\emptyset_{PTL} = \emptyset_{PL} + \frac{2(\emptyset_{\ell\ell})}{P} = (213) + \frac{2(196a)}{(6)}$$
(213b)	B_{PL}	FLUX DENSITY AT BASE OF POLE at 100% load
		$$B_{PL} = \frac{\emptyset_{PTL}}{ap} = \frac{(213a)}{(79)}$$

(213c)	F_{PL}	<u>AMPERE TURNS PER POLE</u> at 100% load $F_{PL} = (\ell_p)\left[\text{AT/in @ density } (B_{PL})\right]$ $= (76)$ [Look up ampere turns/inch on rotor magnetization curve given in (18) at density (213b)]
(221)	ϕ_{g2L}	<u>FLUX CROSSING THE AUXILIARY AIR GAP</u> under load $\phi_{g2L} = (\phi_{PTL})\frac{(P)}{2} + \phi_{7L} + (\phi_{8L})$ $= (213a)\frac{(6)}{2} + (207) + (198b)$
(224)	B_{g2L}	<u>FLUX DENSITY IN AUXILIARY GAP (g_2)</u> under load $B_{g2L} = \frac{(\phi_{g2L})}{(A_{g2})} = \frac{(221)}{(70)}$
(225)	F_{g2L}	<u>AUXILIARY AIR GAP AMPERE TURN DROP</u> under load $F_{g2L} = \frac{(B_{g2L})}{3.19}(g_2) \times 10^3 = \frac{(224)}{3.19}(59a) \times 10^3$
(226)	ϕ_{5L}	<u>COIL LEAKAGE FLUX</u> under load $\phi_{5L} = 2(P_5)\left\{(F_{y2L})+(F_{g2L})+(F_{PL})+(e_d)(F_g) + (F_T)\left[1+\cos(\theta)\right]+(F_c)\right\} \times 10^{-3}$ $= 2(97)\left\{(229)+(225)+(164)+(198)(96) + (97)\left[1+\cos(198a)\right]+(98)\right\} \times 10^{-3}$

(227)	ϕ_{y2L}	FLUX IN END-BELL SECTION OF THE YOKE under load $\phi_{y2L} = (\phi_{g2L})$ $= (221)$
(228)	B_{y2L}	DENSITY IN END-BELL SECTION OF YOKE AT THE SMALLEST AREA SECTION under load $B_{y2L} = \frac{\phi_{y2L}}{A_{y2}} = \frac{(227)}{(124)}$
(229)	F_{y2L}	AMPERE TURN DROP IN END-BELL SECTION OF YOKE under load. $F_{y2L} = \left[\frac{(D)-(d_{y2})}{6}\right] \left[\text{NI/inch @ density } (B_{y2L})\right]$ $= \left[\frac{(12)-(78)}{6}\right] \left[\text{Look up on yoke magnetization curve given in (18) at density (228)}\right]$
(229b)	B_{yL}	FLUX DENSITY IN THE HOUSING SECTION OF THE YOKE under load. $B_{yL} = \frac{(\phi_{g2L}) + (\phi_{5L})}{A_y} = \frac{(221) + (226)}{(124a)}$

(229c)	F_{yL}	**AMPERE TURN DROP THROUGH THE HOUSING SECTION OF THE YOKE** under load using 1/2 total length of housing.
		$F_y = (\ell_y)\left[\text{NI/inch @ density } (B_{yL})\right]$
		$= (78)\left[\text{Look up on yoke magnetization curve given in (18) @ density (229b)}\right]$
(236)	F_{FL}	**TOTAL AMPERE TURN DROP** at full load
		$= 2\left[(F_{g2L})+(F_{yL})+(F_{y2L})+(F_{PL})+(e_d)(F_g) + (F_T)\left[1+\cos(\theta)\right]+F_c\right] \times 10^{-3}$
		$= 2\left[(225)+(229c)+(229)+(213c)+(198)(96) + (97)\left[1+\cos(198a)\right]+(98)\right] \times 10^{-3}$
(237)	I_{FFL}	**FIELD CURRENT** under load
		$I_{FFL} = (F_{FL})/(N_F) = (236)/(146)$
(239)		**CURRENT DENSITY** at 100% load
		Current Density $= (I_{FFL})/(a_{cf}) = (237)/(153)$
(238)	E_{FFL}	**FIELD VOLTS** at 100% load - This calculation is made with hot field resistance at expected temperature at 100% load.
		Field Volts $= (I_{FFL})(R_{f\ hot}) = (237)(155)$

(241) I^2R_{FL} **FIELD I^2R** at 100% load - The copper loss in the field winding is calculated with hot field resistance at expected temperature for 100% load condition.

$$\text{Field } I^2R = (I_{FFL})^2(R_{F\ hot}) = (237)^2(155)$$

(242) W_{TFL} **STATOR TEETH LOSS** at 100% load - The stator tooth loss under load increases over that of no load because of the parasitic fluxes caused by the ripple due to the rotor damper bar slot openings.

$$W_{TFL} = \left\{2\left[.27\frac{(X_d)}{100}\frac{(\%\ \text{Load})}{100}\right]^{1.8} + 1\right\}(W_{TNL})$$

$$= \left\{2\left[.27\frac{(133)}{100}\ 1\right]^{1.8} + 1\right\}(184)$$

(243) W_{PFL} **POLE FACE LOSS** at 100% load

$$W_{PFL} = \left\{\left[\frac{(K_{sc})(I_{PH})\frac{(\%\ \text{Load})}{100}\ (n_s)}{(C)(F_g)}\right]^2 + 1\right\}(W_{PNL})$$

$$= \left\{\left[\frac{(243)(8)\ 1\ (30)}{(32)(96)}\right]^2 + 1\right\}(186)$$

(K_{sc}) is obtained from Curve F-3

(245)	I^2R_L	STATOR I^2R at 100% load - The copper loss based on the D.C. resistance of the winding. Calculate at the maximum expected operating temperature.
		$I^2R = (m)(I_{PH})^2 (R_{SPH\ hot})$
		$= (5)(8)^2 (54)$
(246)	--	EDDY LOSS - Stator I^2R loss due to skin effect
		Eddy Loss $= \left[\frac{(EF_{top}) + (EF_{bot})}{2} - 1\right]$ (Stator I^2R)
		$= \left[\frac{(55) + (56)}{2} - 1\right] (245)$
(247)	--	TOTAL LOSSES at 100% load - sum of all losses at 100% load
		Total Losses = (Field I^2R) + (F&W) + (Stator Teeth Loss) + (Stator Core Loss) + (Pole Face Loss) + (Stator I^2R) + (Eddy Loss)
		= (241) + (183) + (242) + (185) + (243) + (245) + (246)
(248)	--	RATING IN KILOWATTS at 100% load
		Rating $= 3(E_{PH})(I_{PH})$ (P. F.) $\times 10^{-3}$
		$= 3(4)(8)$ (9) $\times 10^{-3}$

(249)	--	RATING PLUS LOSSES = (248) + (247) x 10^{-3}
(250)	--	% LOSSES = $\dfrac{\text{Losses x (100)}}{\text{Rating Plus Losses}}$
		$= \dfrac{(247) \times 10^{-3} \times 10^{2}}{(249)}$
(251)	--	% EFFICIENCY = 100% - % Losses
		= 100% - (250)
		These items can be recalculated for any load condition by simply inserting the values that correspond to the % load being calculated.
		Values for F&W (183) and W_C (Stator Core Loss) (185) do not change with load.